Comparison of CTD vs XBT Data

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INTRODUCTION

The two most common methods in use today of determining ocean temperature profiles with depth are via a Conductivity, Temperature, and Depth (CTD) profiler or via an Expendable Bathythermograph (XBT) probe. CTD profilers are regarded as highly accurate and are used by the scientific community for research purposes. Using the measured temperature values and derived salinity values from a given CTD cast, the sound velocity profile over depth for a sampled location can be computed. The sound velocity profile can then be used to describe the local acoustic environment and predict naval acoustic sensor performance. Unfortunately, the CTD profiler has certain limitations that render it impractical for operational naval applications. First, in order to take a CTD sample a vessel must be at a standstill. Depending on the depth of the water column to be sampled this may require the vessel to remain in place for up to 45 minutes or more, as the CTD is first lowered to depth and then raised to the surface. This requirement is rarely compatible with typical naval operations. Second, the CTD profiler is lowered to depth via a winch system using an electrical conducting cable. Naval vessels are not configured to employ such a system and would require modifications to host a CTD profiler. And third, CTD profiler systems are expensive to operate and maintain.

An XBT probe is a less sophisticated instrument than the CTD profiler, only measuring temperature as it descends through the water column. Depth is computed based on a standard fall rate and a constant, standard salinity is assumed during processing. The XBT is more compatible with naval operations since it does not require the vessel to be at a standstill; XBT probes can be launched at speeds of up to 15 knots. Because the XBT does not have to be retrieved and only measures temperatures on the downcast, data is available sooner than with a CTD. The XBT is deployed either via a handheld launcher or from a small, hull-mounted launch tube. The XBT system is cheaper to operate and maintain than the CTD profiler. Because of its versatility, simplicity, cost, and smaller footprint, the XBT is the method of choice for determining sound velocity profiles for naval operations. However, there is a concern with the accuracy and bias of the XBT probe which would then impact the computation of sound velocity profiles.

The Naval Postgraduate School's winter quarter 2007 Operational Oceanography class (OC3570) conducted a two-leg research cruise aboard the RV Point Sur from 23-30 January, 2007. Leg I departed from Moss Landing, CA on 23 January with half the student class, spent two days in Monterey Bay and then transited along the coast to San Francisco, CA; arriving on 26 January. The second half of the class met the ship in San

Francisco and relieved the students from Leg I. Leg II surveyed San Francisco Bay from 27-28 January and then transited to Monterey Bay; arriving at Moss Landing, CA on 30 January. During the cruise, various different environmental measurements were taken in support of student projects including several CTD and XBT casts.

The aim of this project is to compare the temperature versus depth profiles collected by XBT probes with those measured by the CTD profiler in order to discern any differences or biases which may then in turn impact sound velocity profiles.

DATA COLLECTION

CTD profiles were obtained using the Sea Bird 911+CTD/Rosette (12 position) with standard sensor suite. XBT profiles were obtained using the Sippican Mark 12 XBT system which included the LM-3A Hand Held Launcher. Sippican T-7 XBT probes were used which have a maximum operational depth of 760 m.

During Legs I and II, XBT probes were dropped in the vicinity of selected CTD casts. To make full use of the T-7's maximum operational depth, XBTs were only deployed when the corresponding CTD cast exceeded 760 m. Therefore, XBT launches were confined to Monterey Bay Canyon and offshore stations and none were made within the shallow water areas of Monterey Bay or

in San Francisco Bay. Over the course of the cruise, 25 pairs of CTD/XBT profiles were identified.

Appendix A contains the location of each CTD/XBT pair. Appendix B contains a graphical depiction of the location of each CTD/XBT pair.

DATA QUALITY CONTROL

Once the 25 available pairs of CTD/XBT profiles were identified, the raw data for each cast was examined. CTD data is recorded in ASCII text format (.asc) while XBT data is recorded in European data format (.edf). It should be noted that CTD depth data is recorded in dbars while XBT depth data is recorded in meters and must be adjusted accordingly when processing the data.

Using the final cruise report and looking at the raw data files, it was found that one XBT was erroneously processed as a T-6 vice T-7 XBT (data was recorded to only 460 m), one XBT failed during deployment, one CTD cast failed due to an electrical short, and one pairing was over 4 km apart and deemed not representative of the same water column. These four pairings were not used in the data comparisons, leaving 21 viable CTD/XBT pairs.

Using MATLAB 6.5, temperature vs depth was plotted for each of the 21 CTD/XBT pairs and then visually inspected. The first

immediate error noted was a temperature jump at the end of some of the XBT files. When an XBT reaches maximum depth, a jump in temperature is observed as the copper conducting wire breaks and the electrical signal spikes. These temperature jumps were removed from all XBT files. In addition, CTD cast 23 revealed a decibar measurement of 0.000 at approximately 336 m which was readily evident when plotted. A default value was inserted for the missing reading by interpolating between the readings above and below this depth.

XBT 19 revealed a suspect warming trend below 670 m; the only XBT to show this type of feature. Because the warming was gradual and not an obvious spike in the data (see Figure 1) it was decided to retain the XBT for comparison, however, computation runs were made with and without XBT 19 to see if there was any difference.

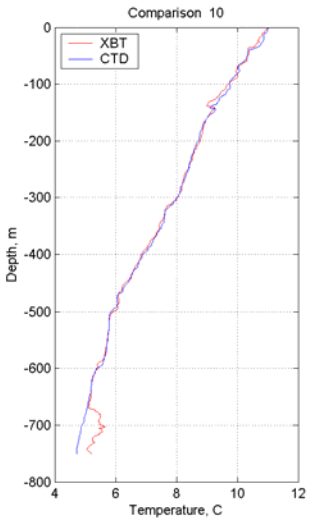

Figure 1

In addition to plotting the data and observing any visual differences, the horizontal separation distance between each CTD and XBT pairing was computed from the recorded latitude and longitude for each cast. Five pairings were flagged due to being over 1 km apart.

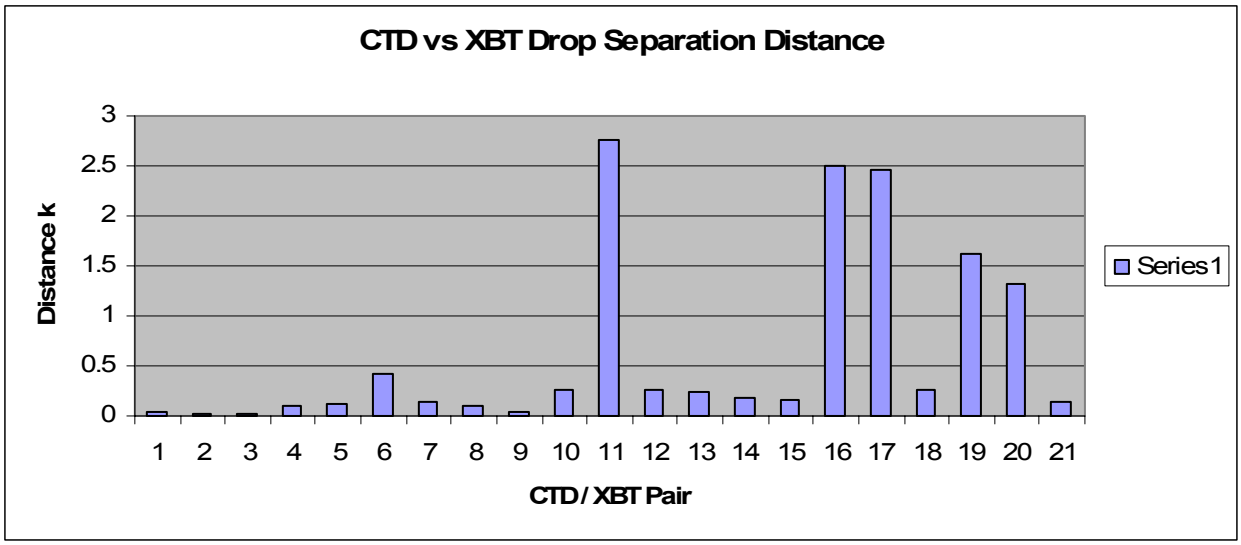

Figure 2

A visual inspection of the data and comparison of the CDT/XBT temperature plots for pairings 11, 16, 17, 19, and 20 did not indicate substantial differences and thus were included with the remaining pairs. However, when the data was processed two runs were made for comparison - one which included all 21 pairs and one with the above five flagged pairs excluded.

METHODS OF DATA PROCESSING

Because of the high accuracy and known calibration of the Sea Bird CTD profiler, the CTD profiler is considered to

represent the true temperature and salinity depth profile for the stations sampled during this cruise. Temperature comparisons were made between the CTD and XBT for the same depth and any differences were assumed to be due to the inaccuracy of the XBT.

Because the XBT probe measures depth in meters and the CTD profiler measures depth in decibars, the first necessary step was to convert the CTD pressure readings to meters to allow for direct comparisons. A MATLAB routine was used to extract the CTD pressure values and convert them to depth in meters.

The second step was to adjust for sampling rates between the CTD and XBT. In order to compare the temperature values between the CTD and XBT, the temperature values from each data set must be at the same depth. The CTD profiler took temperature readings approximately every meter as it descended, while the XBT probe took temperature readings approximately every 0.64 meters. An interpolation routine was run in MATLAB to allow for temperature comparisons at equal depths.

Once the above adjustments were made to the data, a direct comparison could be made between CTD and XBT temperature readings. As mentioned previously, the CTD temperature was assumed to represent truth against which the XBT was compared. XBT temperatures for each depth were subtracted from the CTD temperature values. Appendix C contains the plots of each pair

of CTD/XBT temperature readings along with the temperature difference between the two instruments.

For each CTD/XBT pair, the mean and standard deviation was calculated for each depth, which was then incorporated into an overall mean and standard deviation for the entire data set. Appendix D contains the mean and standard deviation results.

The XBT extraction program calculates sound velocity based on the obtained temperature vs depth readings and an assumed salinity of 30 psu. The seawater sound velocity m-file (sw-svel.m) was used in MATLAB to compute sound velocity from the CTD data using the measured temperature, salinity, and pressure values obtained during the cast. The sound velocity profile for each sample and the difference for each pair was plotted in MATLAB. Appendix C contains the plots for each pair. In addition, the mean and standard deviation of the sound velocity calculations for the entire set is included in Appendix D.

It was noted earlier that five of the CTD/XBT pairs had separation distances within each pair over 1 km apart. In order to see if these five pairs had any significant impact on the overall mean and standard deviation, the comparisons were re-run excluding these suspect CTD/XBT pairs – resulting in 16 useable pairs. In addition, XBT 19 exhibited a temperature deviation at depth (see Figure 1) and was also considered suspect. The

comparisons were then re-run excluding the CTD23/XBT19 pair – resulting in 20 and 15 useable pairs. Appendix D contains the mean and standard deviation results for temperature and sound velocity from these alternate data sets.

As a last comparison, empirical orthogonal functions were computed for the 21 pairs of CTD, XBT, temperature difference and sound velocity differences to analyze the variation in the principle components. The results are contained in Appendix E.

RESULTS

The results of the CTD/XBT temperature and sound velocity comparisons are summarized in Tables 1 & 2. Over the depth of the water column the 21 XBT probes ranged from 0.0271 ^{0}C colder to 0.1270 ^{0}C warmer than measured CTD temperatures, with an overall average value of 0.0344 ^{0}C warmer. The coldest XBT readings occurred at depths greater than 400 m, while the warmest readings were all at the surface. The standard deviation ranged from 0.2351 ^{0}C to 0.0257 ^{0}C with an overall mean standard deviation of 0.1012 ^{0}C. The greatest variation occurred in the upper 70 m of water while the least variation typically occurred at 500 m. From the plots in Appendix C these results can be seen visually with the greatest variability seen from the surface to 100 m and below 700 m, while the middle of the water column yields the most stable results. The differences in sound

velocity are included in Table 2. Sound velocity differences varied from a maximum of 5.665 m/s at approximately 600 m to a minimum of 3.63 m/s at the surface, corresponding to the maximum and minimum temperature measured differences. The warm bias of the XBT probes resulted in an average sound velocity 5.06 m/s slower than that computed by the CTD profiler.

When comparing the full data set of 21 CTD/XBT pairs to the reduced data sets, the standard deviation improved however the warm temperature bias increased from 0.0344 to 0.0425 ^{0}C. The results were similar enough, however, that no reason to exclude the full data set of 21 CTD/XBT pairs was justified.

	21 Pairs	20 pairs	16 pairs	15 pairs
Mean T diff (^{0}C)	-0.034365	-0.034342	-0.041981	-0.042459
Max cold XBT (^{0}C)	0.0271	0.0208	0.0150	0.0122
Depth level (m)	593	594	590	404
Max warm XBT (^{0}C)	-0.1270	-0.1354	-0.1271	-0.1383
Depth level (m)	1	1	1	1
Mean T StdDev	0.10119	0.095355	0.098326	0.090849
Max T StdDev	0.2351	0.2403	0.2522	0.2602
Depth level	68	68	69	69
Min T StdDev	0.0527	0.0517	0.0499	0.0420
Depth level	499	499	260	9

Table 1

CTD/XBT Temperature Differences

	21 Pairs	20 pairs	16 pairs	15 pairs
Mean SSV diff (m/s)	5.0608	5.0628	5.0282	5.0287
Max SVP diff (m/s)	5.6653	5.7080	5.6141	5.6456
Depth level (m)	593	732	590	731
Min SVP diff (m/s)	3.6301	3.6035	3.6473	3.6129
Depth level (m)	1	1	1	1
Mean SSV StdDev	0.39807	0.37427	0.38898	0.35914
Max SVP StdDev	0.9049	0.9255	0.9726	1.0027
Depth level	68	69	69	69
Min SVP StdDev	0.2207	0.2189	0.1920	0.1752
Depth level	445	449	260	702

Table 2

CTD/XBT Sound Velocity Differences

COMPARISON WITH PREVIOUS STUDENT STUDIES

Previous student comparisons obtained similar results. All showed a warm bias in the XBT measured temperatures as compared to the temperatures measured by the CTD profiler and each study obtained similar standard deviations. Table 3 summarizes the mean temperature and standard deviations from this study and previous studies. The Sippican corporation claims an accuracy of ±0.1 ^{0}C in their XBT probe product brochure which this study verified, but is slightly outside the average deviation when combined with the results of the six previous student studies. Some of the previous studies also explored in further depth the

warm bias in the upper 100 m of the water column, however this study did not separate the data in this manner.

Author, Yr (sample size)	Mean T diff(^{0}C)	Std Dev (^{0}C)
Schmeiser, 2000 (18)	-0.1549	0.2151
Roth, 2001 (9)	-0.0783	0.1047
Boedeker, 2001 (27)	-0.0882	0.2147
Fang, 2002 (28)	-0.1074	0.1546
Dixon, 2003 (24)	-0.1275	0.0598
Laird, 2006 (13)	-0.0407	0.0936
Whelan, 2007 (21)	-0.0344	0.1012
Average	**-0.0902**	**0.1348**

Table 3

Previous Student Results

DISCUSSION

The results and conclusions of this study are consistent with the six previous studies in the measurement of the CTD/XBT temperature differences and standard deviation. However, the previous studies claim sound velocity differences on the order of 0.163 ~ 0.51 m/s based on the calculation in Schmeiser (2000), where it was calculated that a bias of 0.4 °C would change the computed sound speed by 1.6 m/s or approximately 0.1% of the average 1500 m/s sound velocity of sea water. Based on

this calculation the measured sound velocity differences from the current study should be on the order of 0.14 m/s. This study however, used the sound velocity program in MATLAB to compute sound velocity based on the CTD and XBT data collected during this cruise. The average sound velocity differences based on CTD and XBT temperature differences were on the order of 5.06 m/s vice 0.163 ~ 0.51 m/s. Despite the large discrepancy between this study and previous studies on the computed effect of CTD/XBT temperature differences on sound velocity, the overall impact of this difference results in changes on the order of only 0.34% of the 1500 m/s average value of sound speed in sea water.

The warm bias in XBT measurements is of concern to scientific research and must be accounted for in any studies that use XBT data in conjunction with CTD data. However, as concluded in previous student studies, this warm bias is not significant to naval operations and XBT probes remain a viable method for quickly and cheaply determining the sound velocity profile for a given operating area.

REFERENCES

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Valeport
http://www.valeport.co.uk/Notes/CTD%20vs%20SV%20040915%20.htm

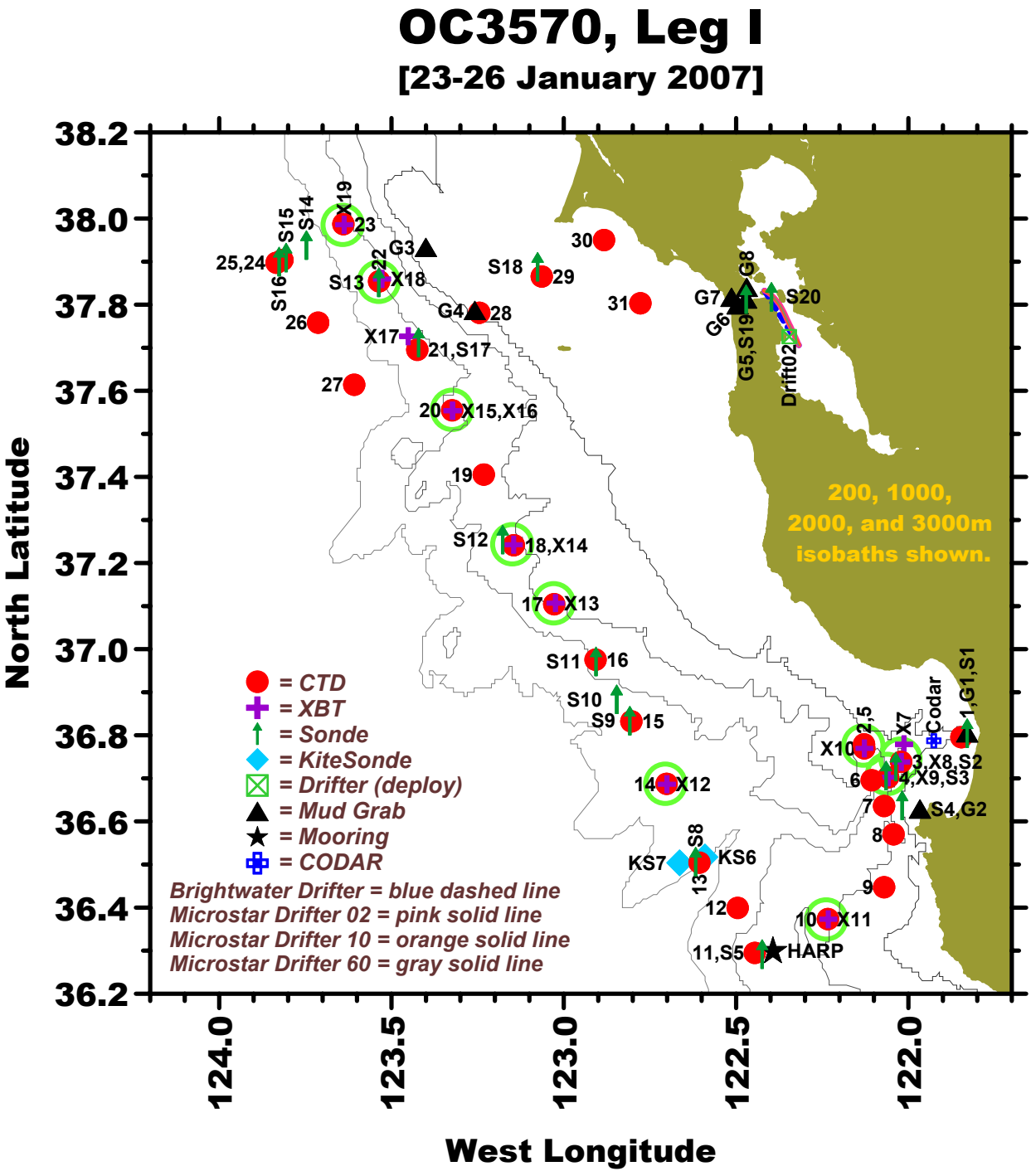
Windows to the Universe, CTD Instruments
http://www.windows.ucar.edu/tour/link=/earth/Water/CTD.html&edu=high

APPENDIX A

Comparison	Probe	Latitude	Longitude	Depth XBT/CTD - m/dbar	Distance (m)
1	XBT 8	36-44.28	122-01.24	760.4	47
	CDT 3	36-44.30	122-01.26	1010.9	
2	XBT 9	36-42.15	122-03.52	760.4	30
	CDT 4	36-42.15	122-03.54	1423.0	
3	XBT 10	36-46.18	122-07.66	760.4	30
	CDT 5	36-46.18	122-07.68	1010.0	
4	XBT 11	36-22.37	122-13.96	760.4	97
	CDT 10	36-22.39	122-14.02	1012.3	
5	XBT 12	36-41.19	122-42.05	760.4	119
	CDT 14	36-41.24	122-42.10	1011.0	
6	XBT 13	37-06.41	123-01.45	760.4	428
	CDT 17	37-06.26	123-01.67	1011.7	
7	XBT 14	37-14.56	123-08.72	760.4	149
	CDT 18	37-14.48	123-08.71	1011.3	
8	XBT 16	37-33.25	123-19.39	760.4	92
	CDT 20	37-33.28	123-19.44	1010.0	
9	XBT 18	37-51.57	123-31.66	760.4	941
	CDT 22	37-51.25	123-32.16	1011.0	
10	XBT 19	37-59.14	123-38.24	760.4	252
	CDT 23	37-59.22	123-38.38	1011.0	
11	XBT 20	37-28.98	123-28.62	760.4	2769
	CDT 64	37-28.23	123-30.25	1012.0	
12	XBT 21	37-10.89	123-17.91	760.4	267
	CDT 66	37-11.01	123-18.01	1011.8	
13	XBT 22	37-02.24	123-11.67	760.4	248
	CDT 67	37-02.28	123-11.83	1011.0	
14	XBT 23	36-53.54	123-05.24	760.4	185
	CDT 68	36-53.60	123-05.34	1013.3	
15	XBT 24	36-44.76	122-59.04	760.4	166
	CDT 69	36-44.85	122-59.04	1011.5	
16	XBT 25	36-34.95	122-52.09	760.4	2498
	CDT 70	36-36.18	122-52.78	1011.0	
17	XBT 26	36-26.20	122-46.52	760.4	2461
	CDT 71	36-27.52	122-46.33	1010.0	
18	XBT 27	36-29.08	122-19.07	760.4	256
	CDT 73	36-29.13	122-19.23	1010.9	
19	XBT 28	36-36.85	122-24.66	760.4	1629
	CDT 74	36-37.62	122-25.19	1012.0	
20	XBT 29	36-45.54	122-30.88	760.0	1328
	CDT 75	36-46.20	122-31.23	1011.0	
21	XBT 30	36-38.57	122-07.26	760.4	135
	CDT 78	36-38.56	122-07.35	2126.7	

APPENDIX B

CTD/XBT pairs used for comparisons indicated by green circles.



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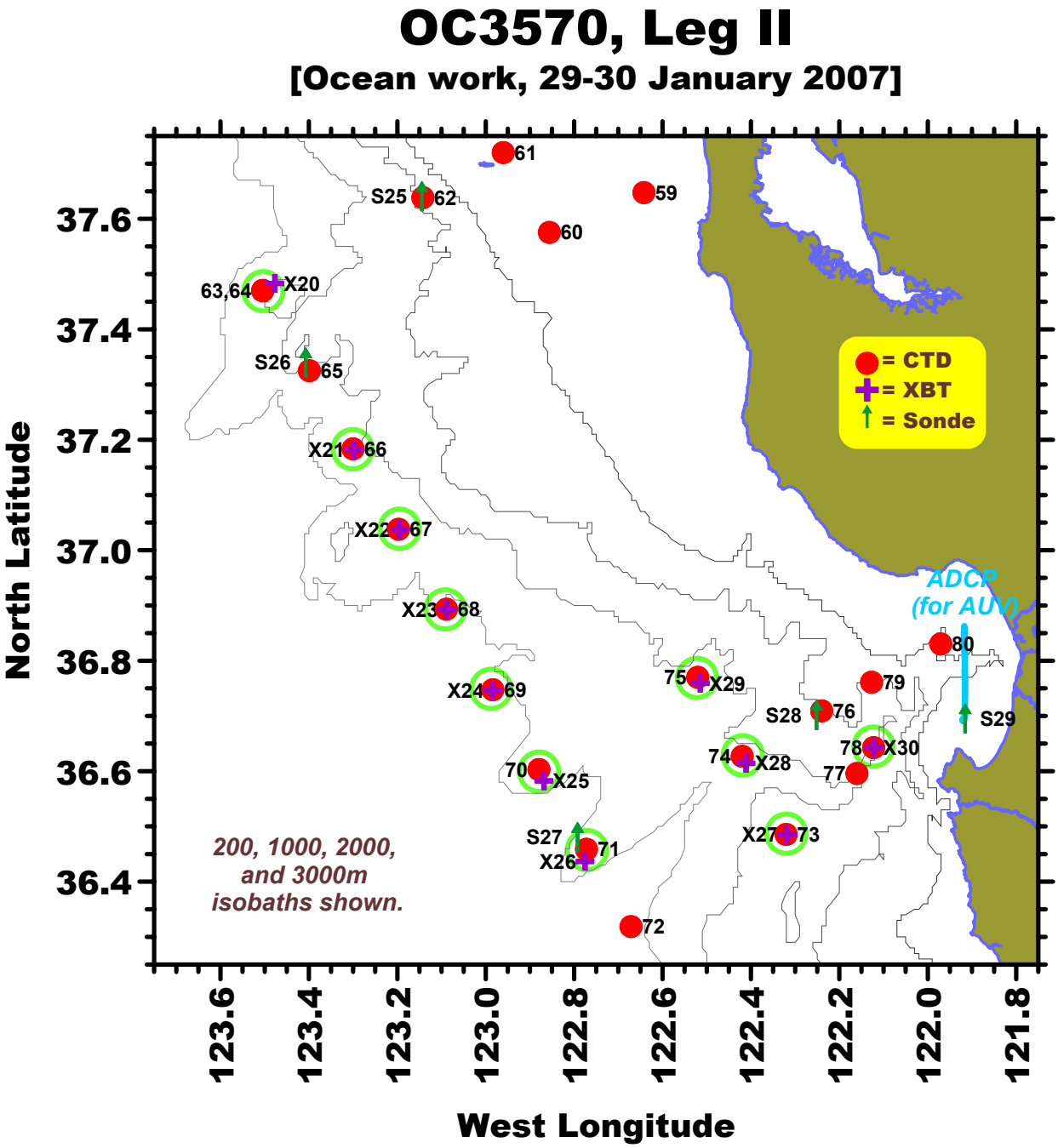
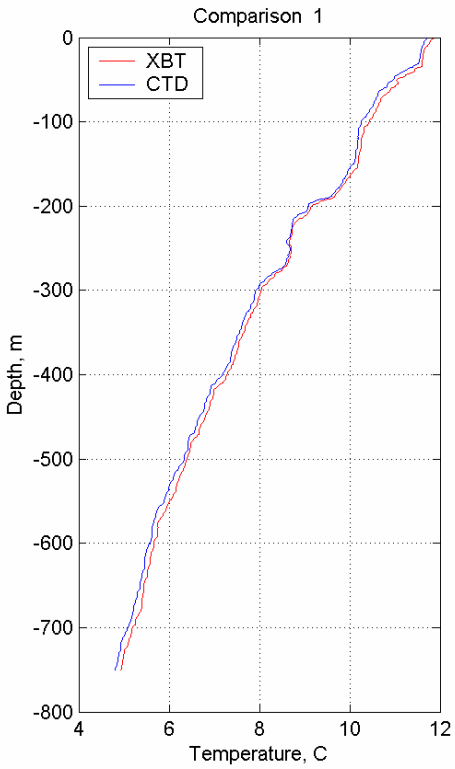
CTD/XBT pairs used for comparisons indicated by green circles.



APPENDIX C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XBT
CTD
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Temperature, C
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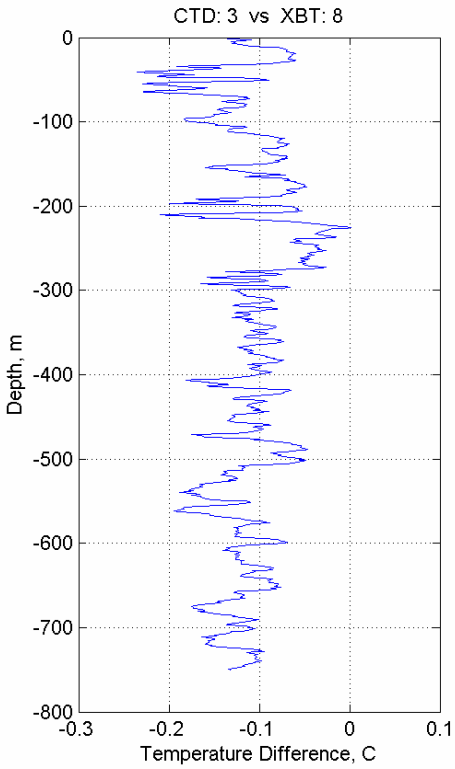
6
8
10
12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Temperature Difference, C
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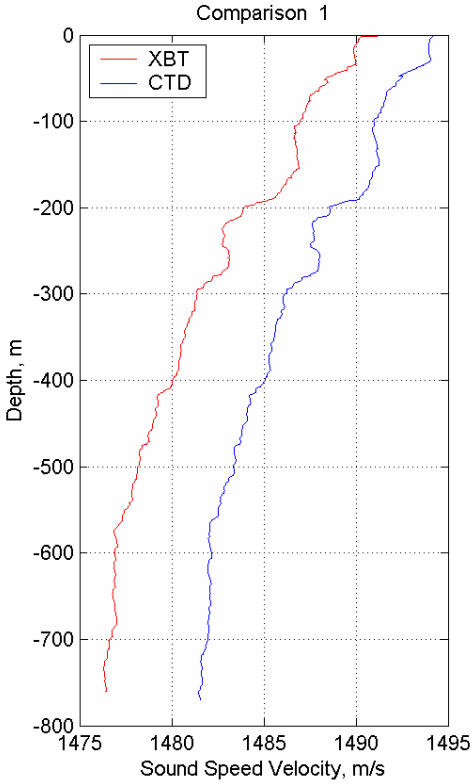
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CTD
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Sound Speed Velocity, m/s
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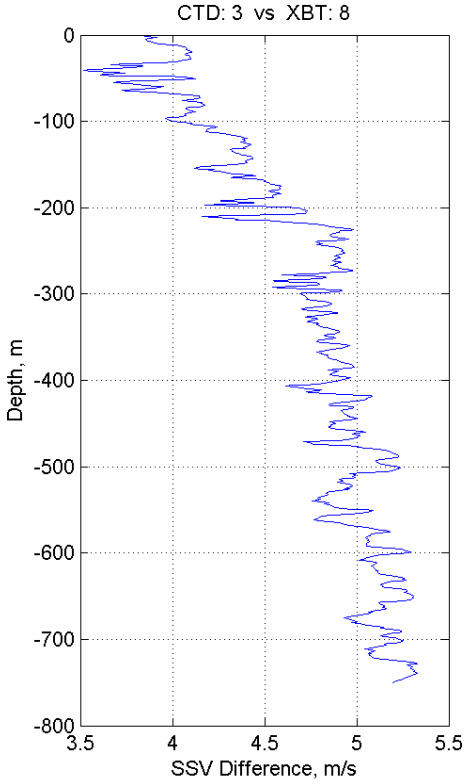
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Depth, m
SSV Difference, m/s
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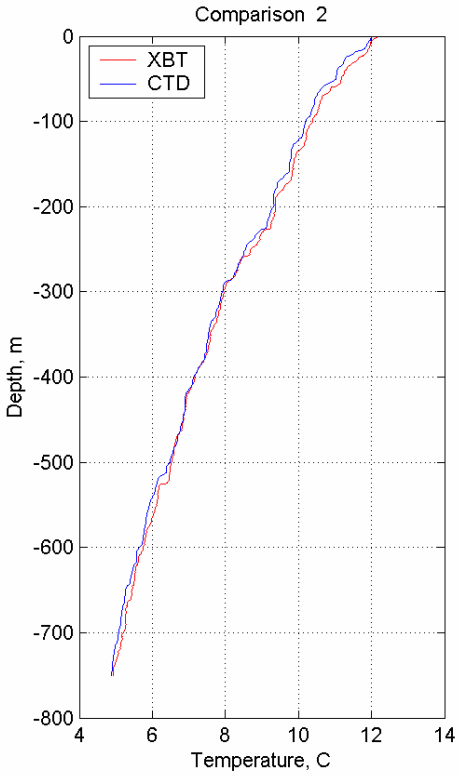
5.5

APPENDIX C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CTD
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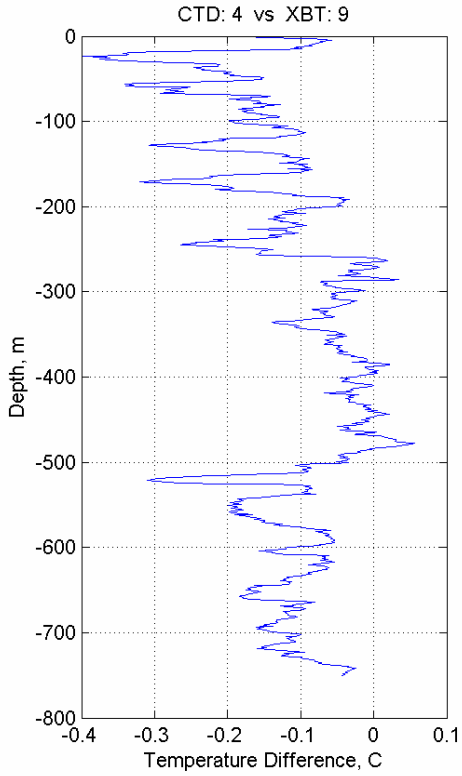
10
12
14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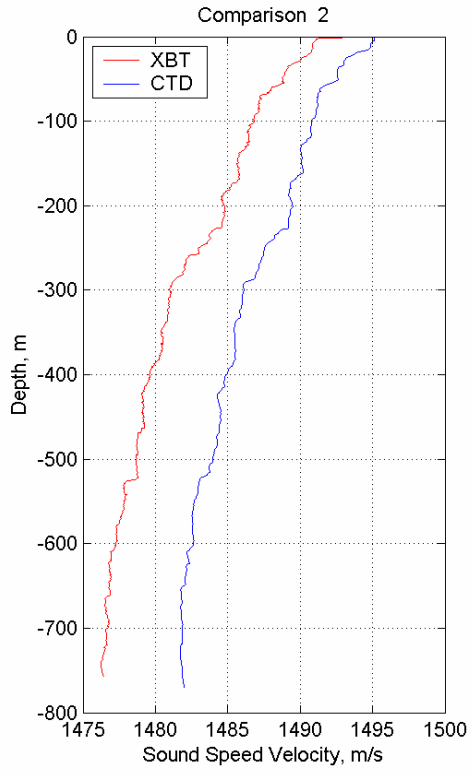
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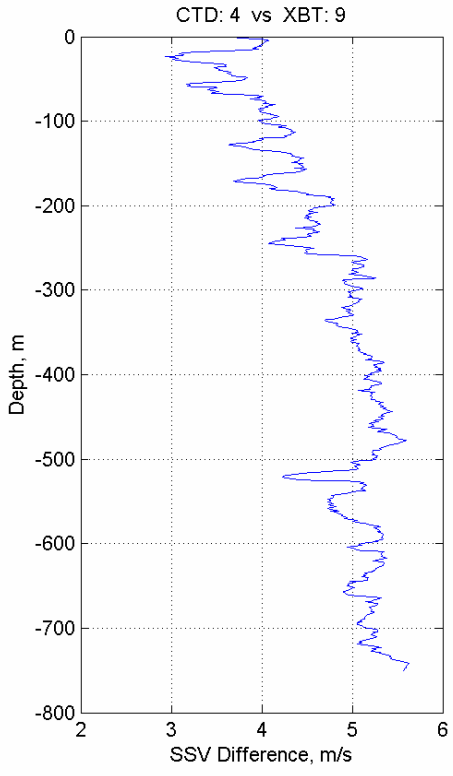
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SSV Difference, m/s
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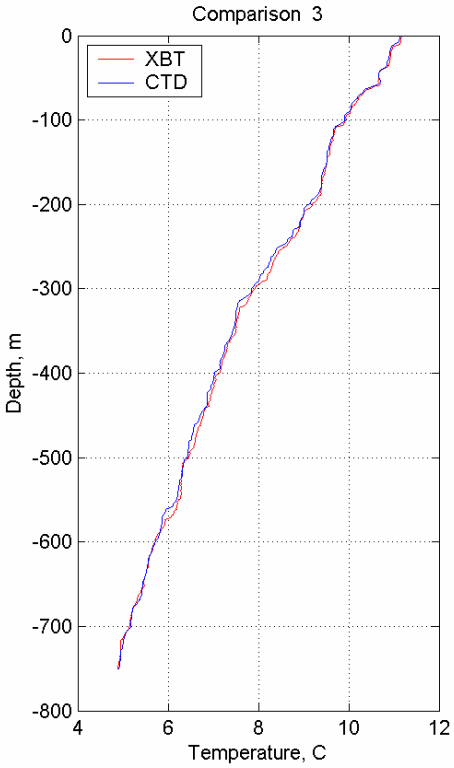
2
3
4
5
6

APPENDIX C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XBT
CTD
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8
10
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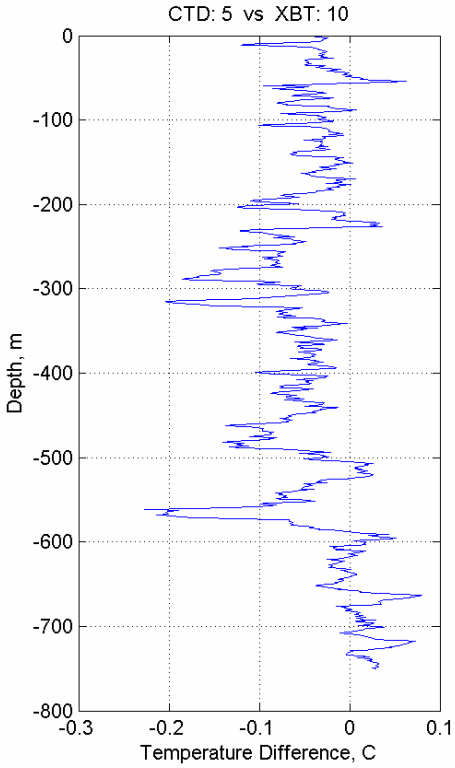
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Temperature Difference, C
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-600
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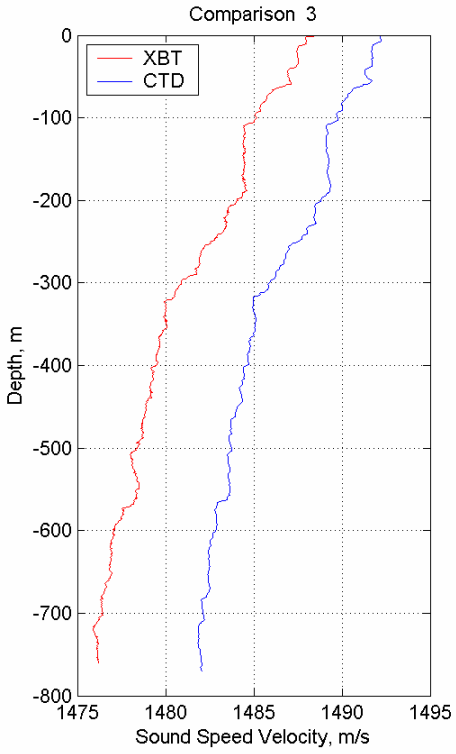
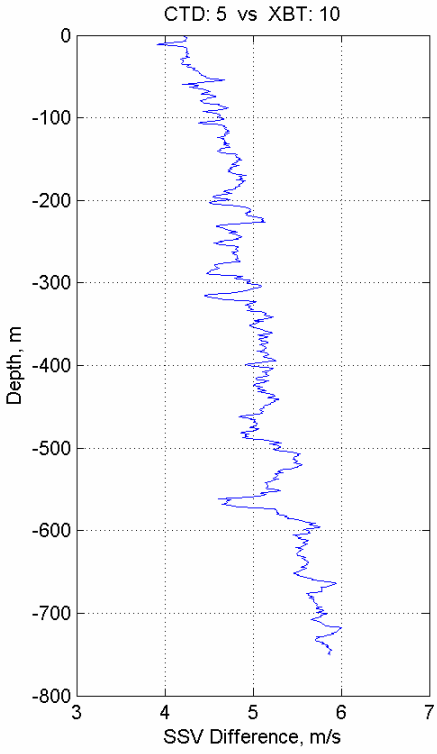
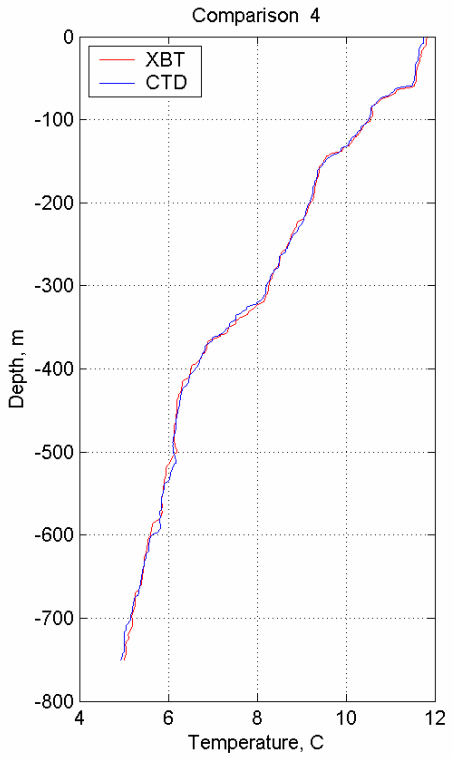
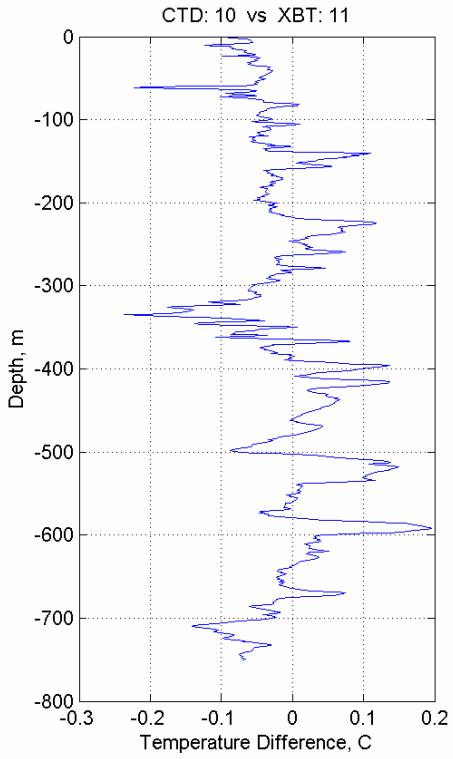
-0.2
-0.1
0
0.1

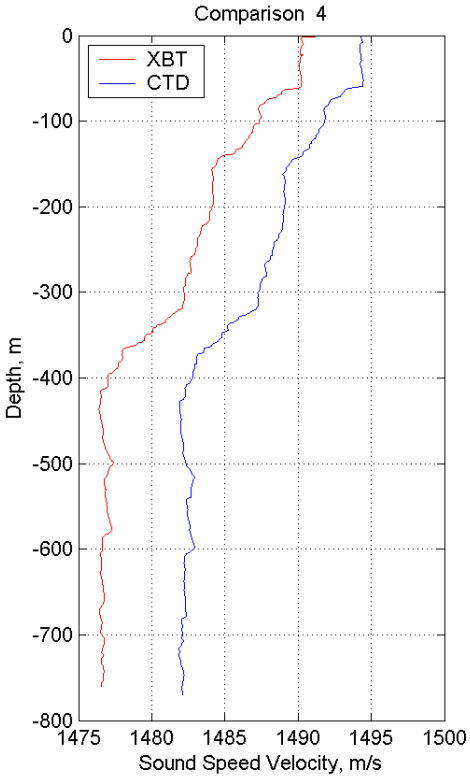

Comparison 3
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495

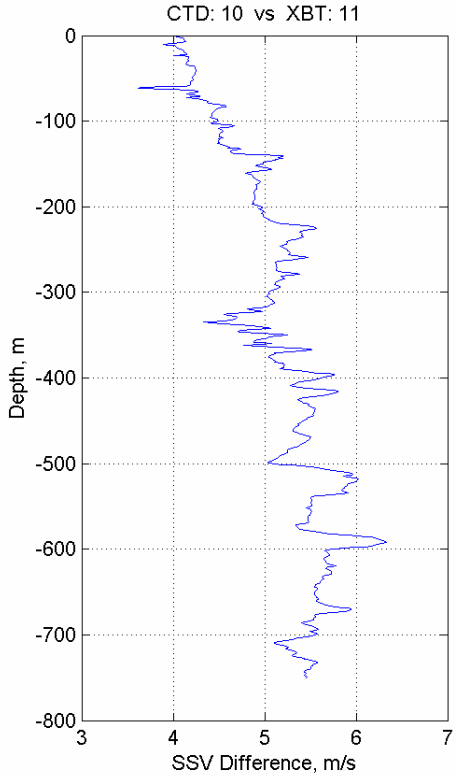

CTD: 5 vs XBT: 10
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

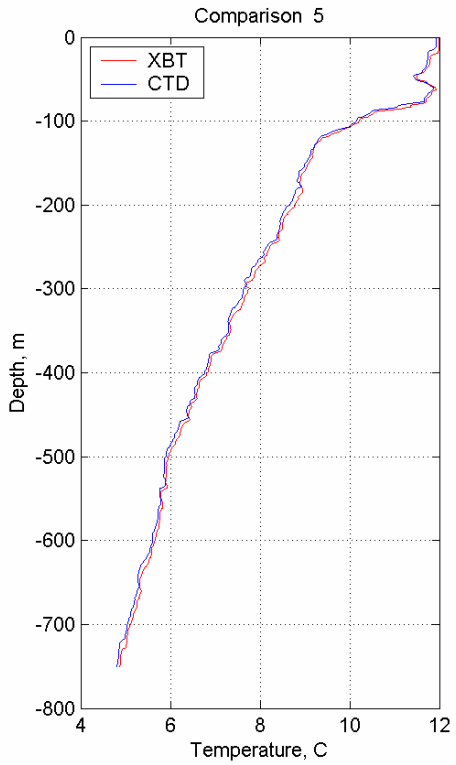

Comparison 4
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

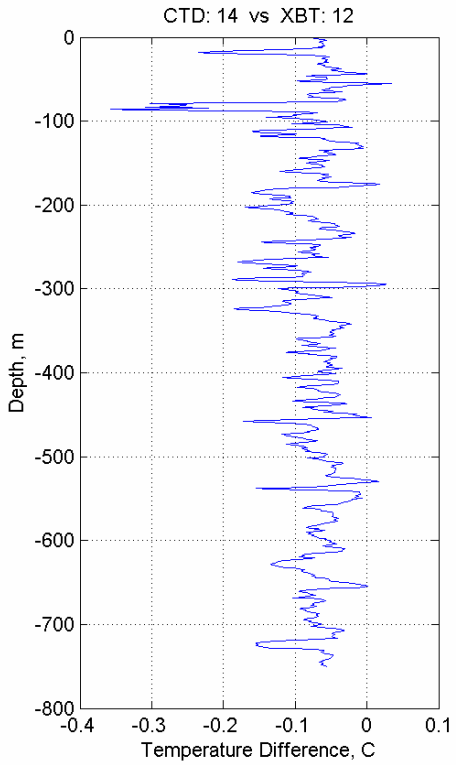

CTD: 10 vs XBT: 11
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.3
-0.2
-0.1
0
0.1
0.2

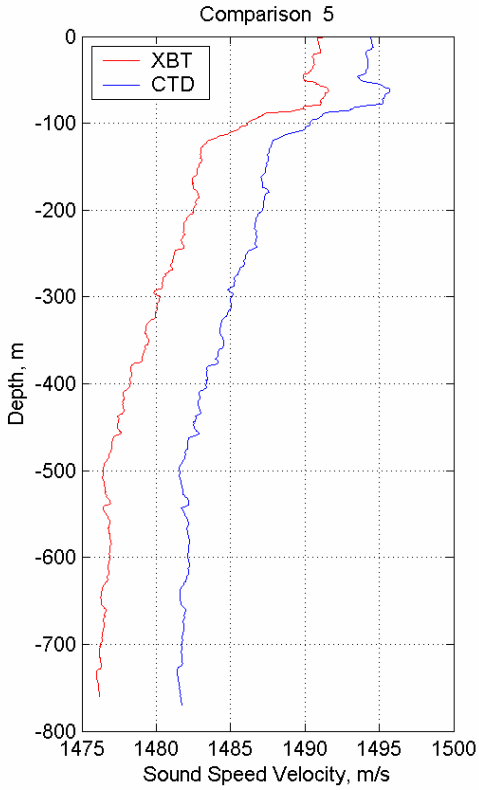

Comparison 4
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
1500

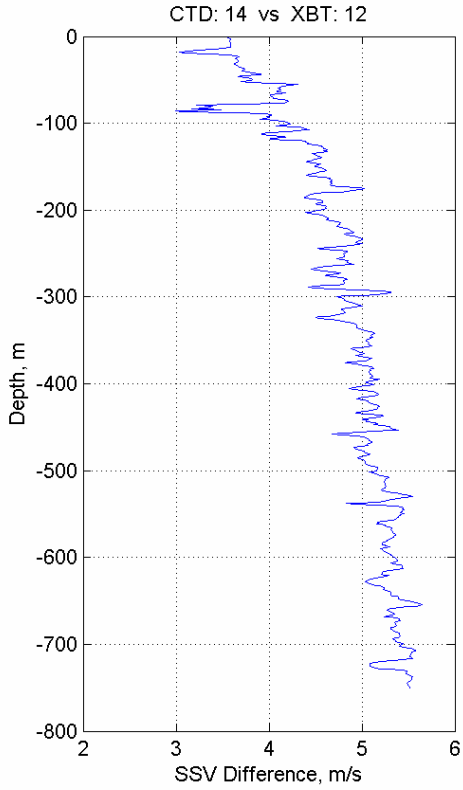

CTD: 10 vs XBT: 11
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

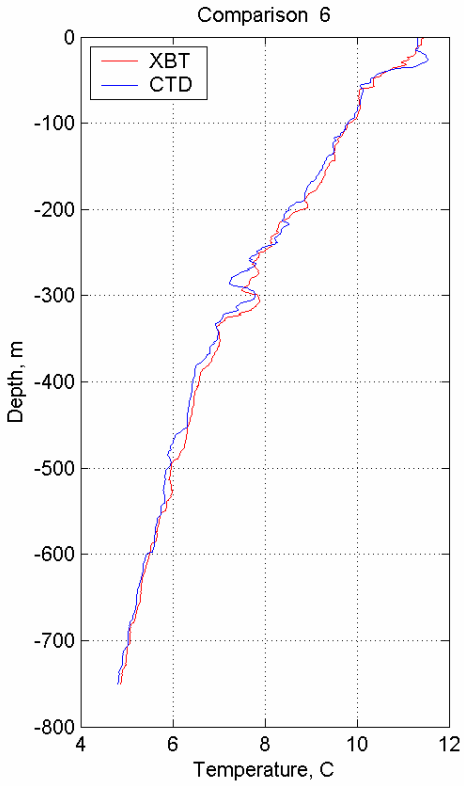

Comparison 5
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

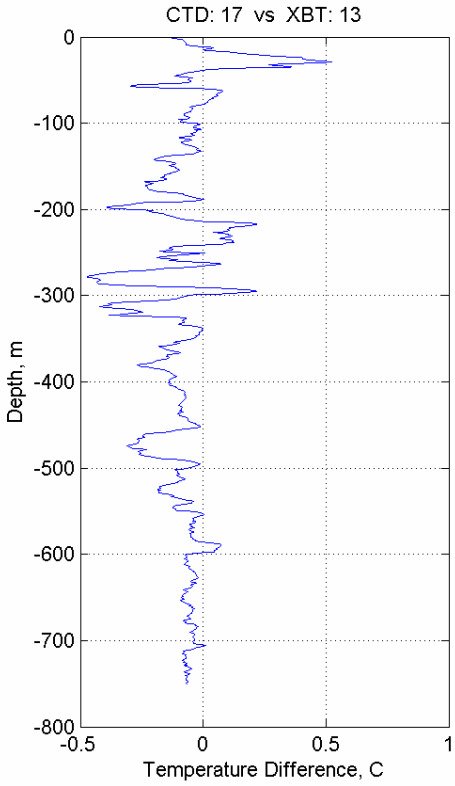

CTD: 14 vs XBT: 12
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.3
-0.2
-0.1
0
0.1

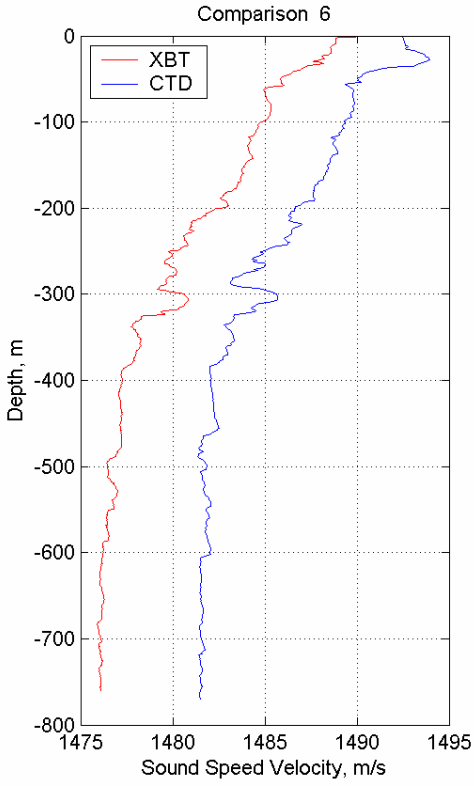

Comparison 5
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
1500

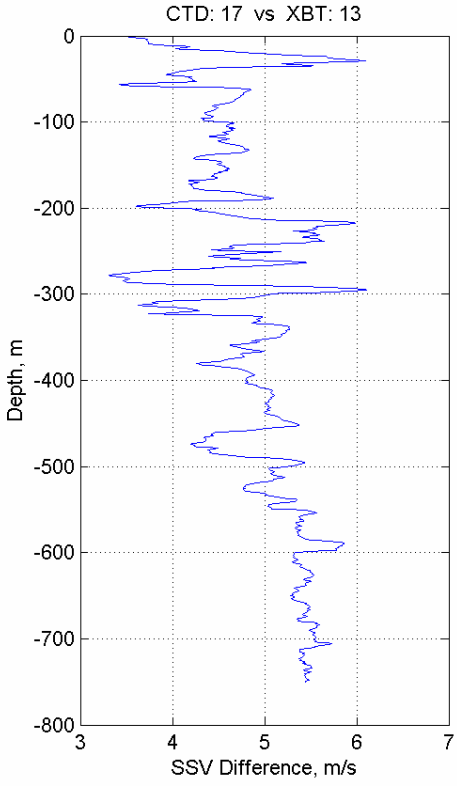

CTD: 14 vs XBT: 12
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
2
3
4
5
6

APPENDIX C

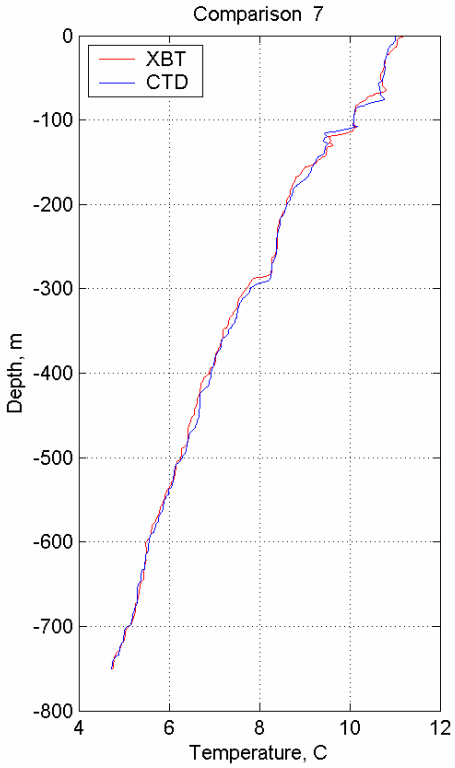

Comparison 6
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

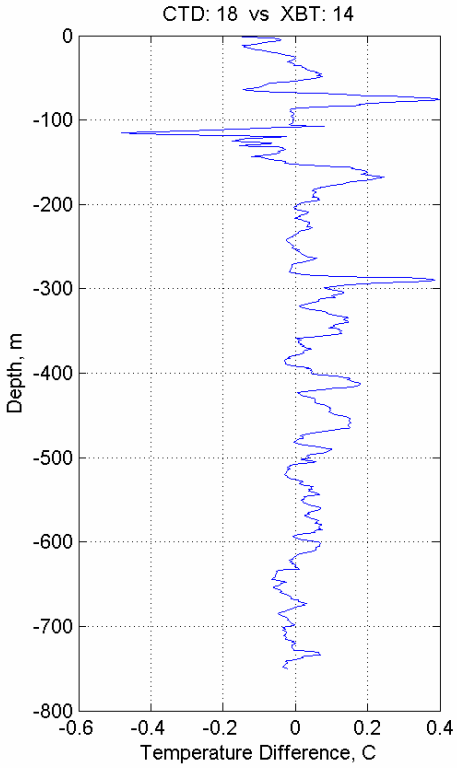

CTD: 17 vs XBT: 13
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.5
0
0.5
1

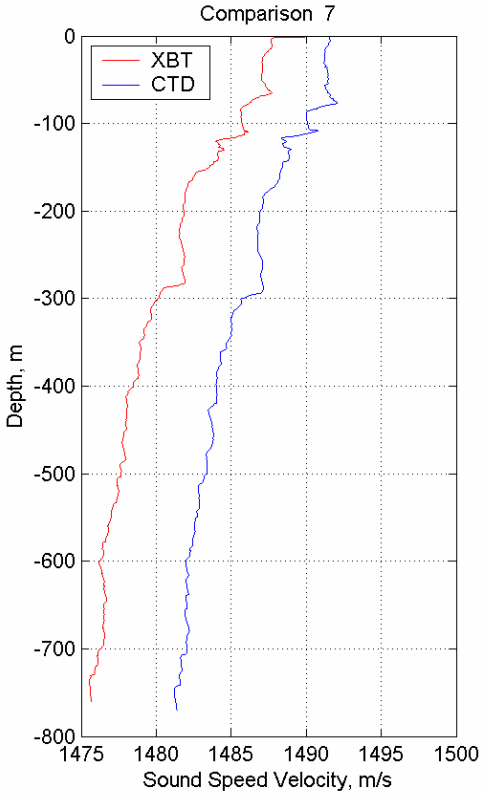

Comparison 6
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495

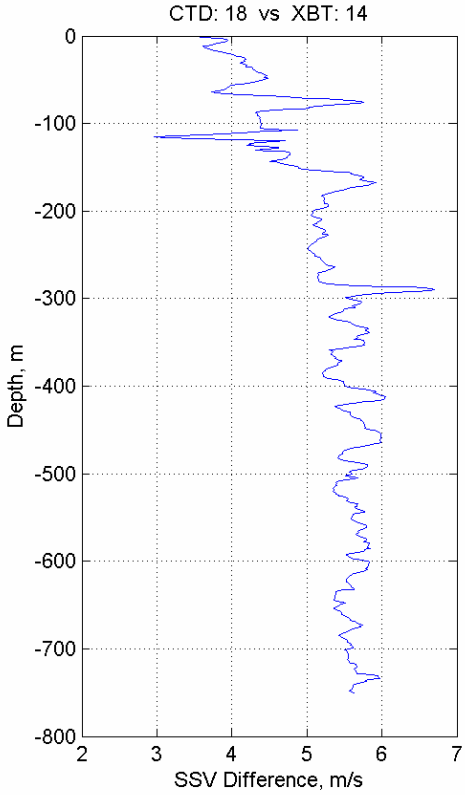

CTD: 17 vs XBT: 13
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

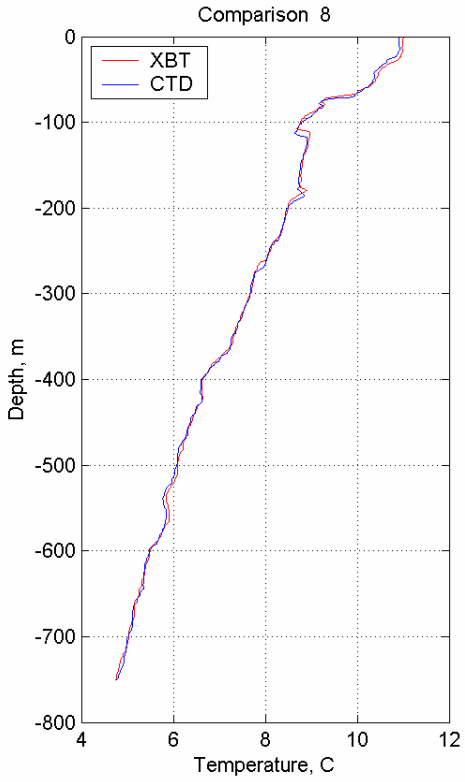

Comparison 7
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

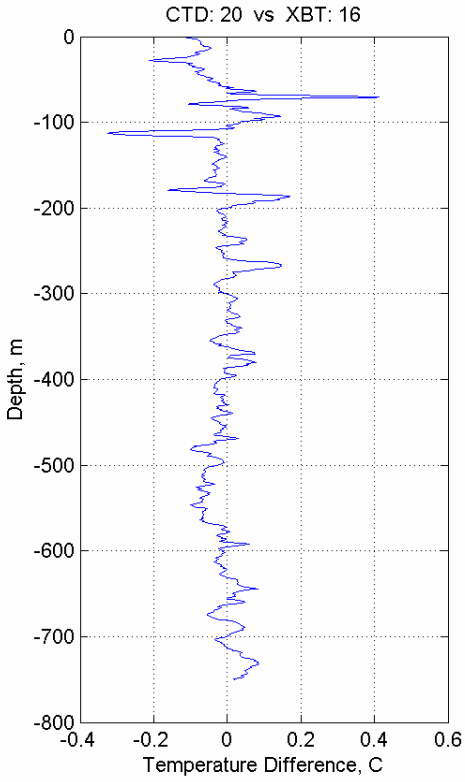

CTD: 18 vs XBT: 14
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.6
-0.4
-0.2
0
0.2
0.4

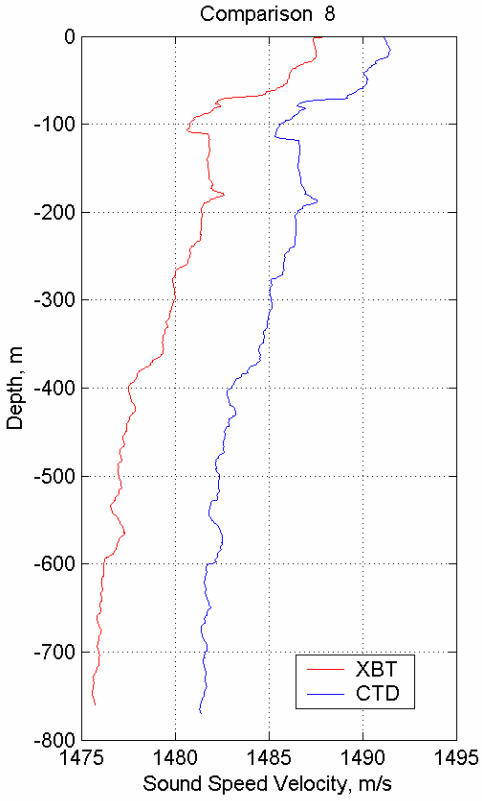

Comparison 7
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
1500

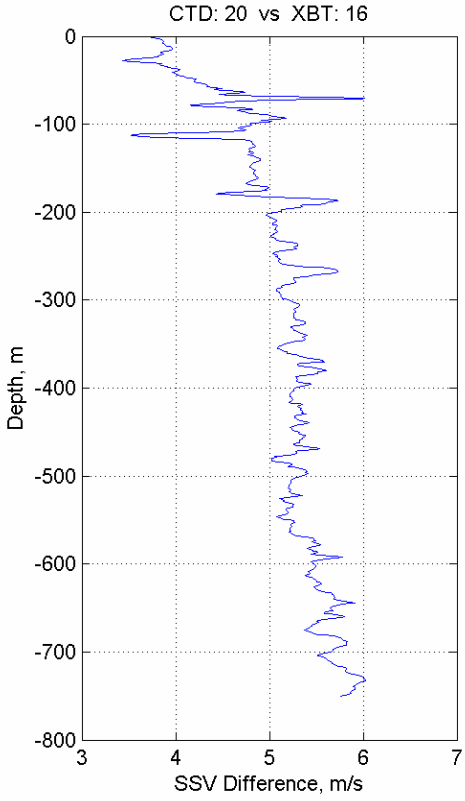

CTD: 18 vs XBT: 14
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
2
3
4
5
6
7

APPENDIX C

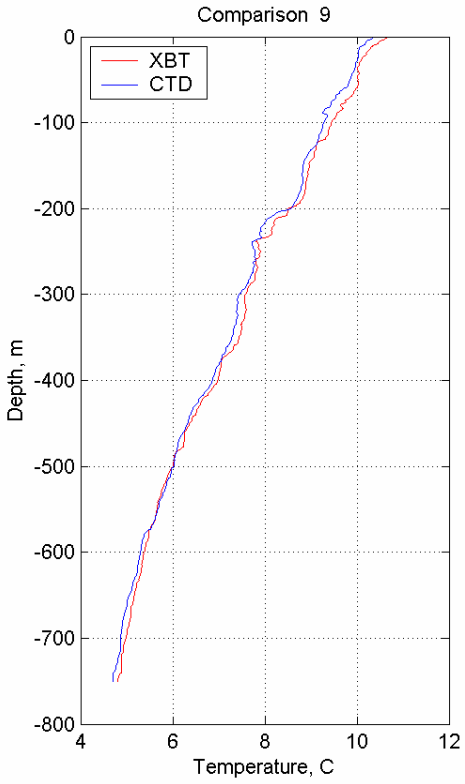

Comparison 8
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

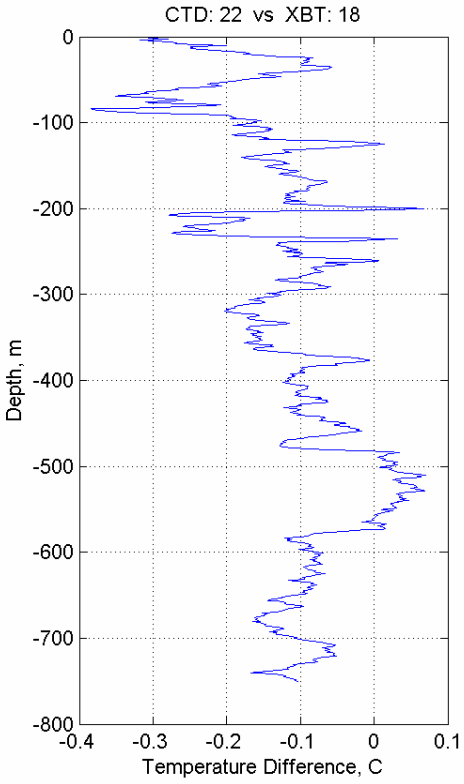

CTD: 20 vs XBT: 16
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.2
0
0.2
0.4
0.6

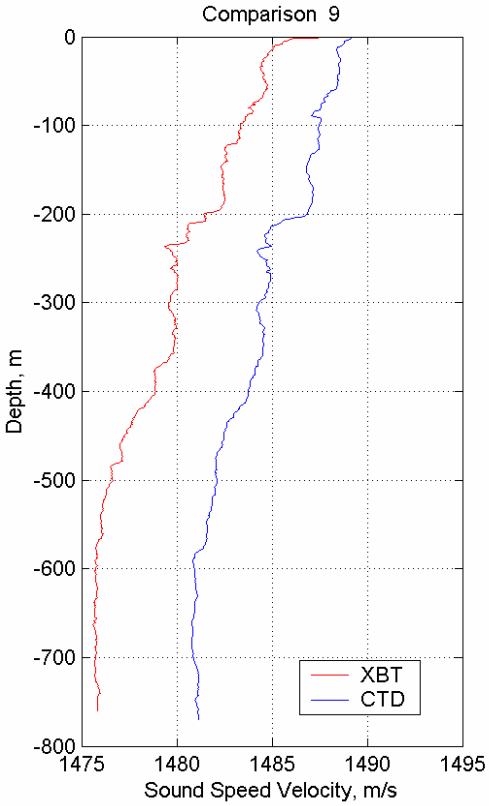

Comparison 8
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495

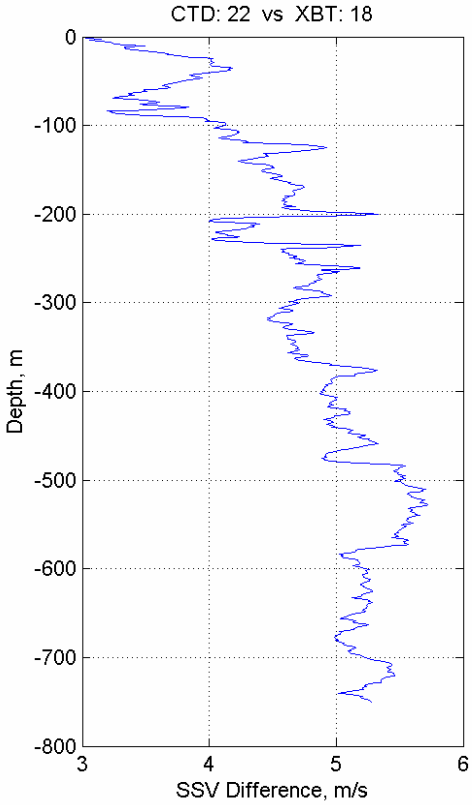

CTD: 20 vs XBT: 16
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

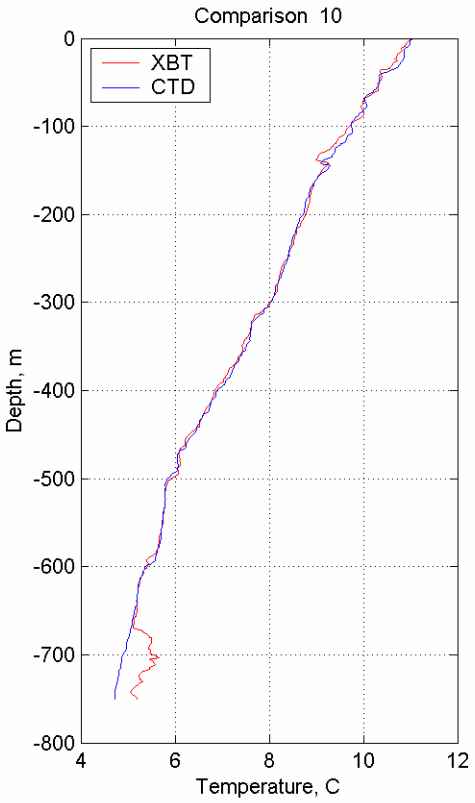

Comparison 9
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

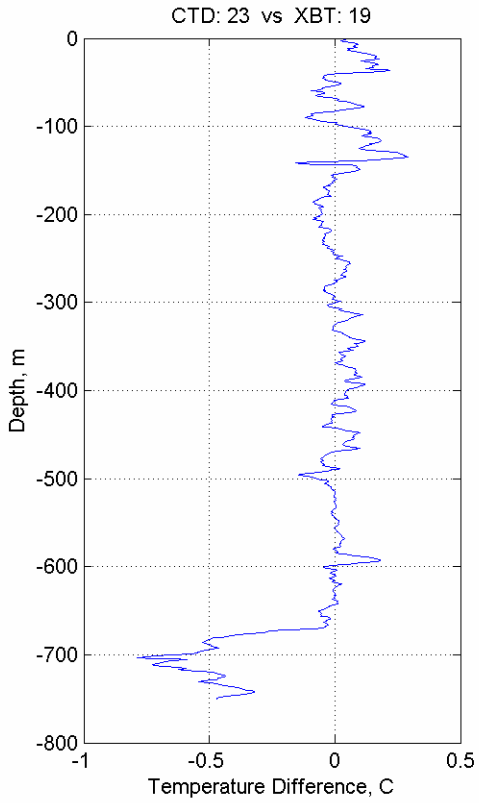

CTD: 22 vs XBT: 18
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.3
-0.2
-0.1
0
0.1

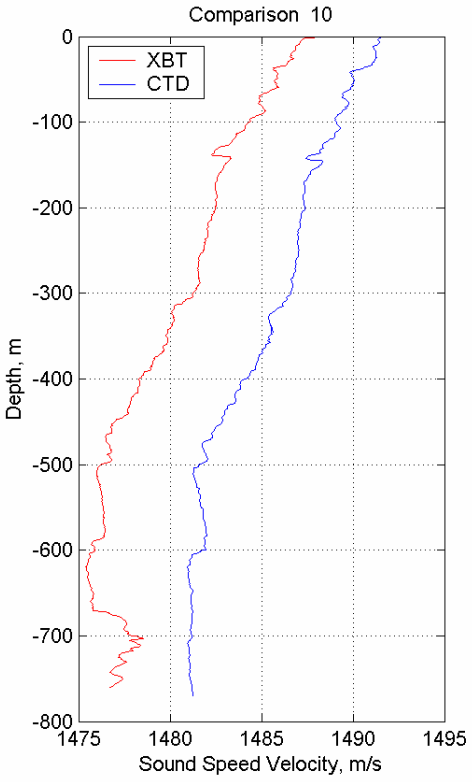

Comparison 9
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495

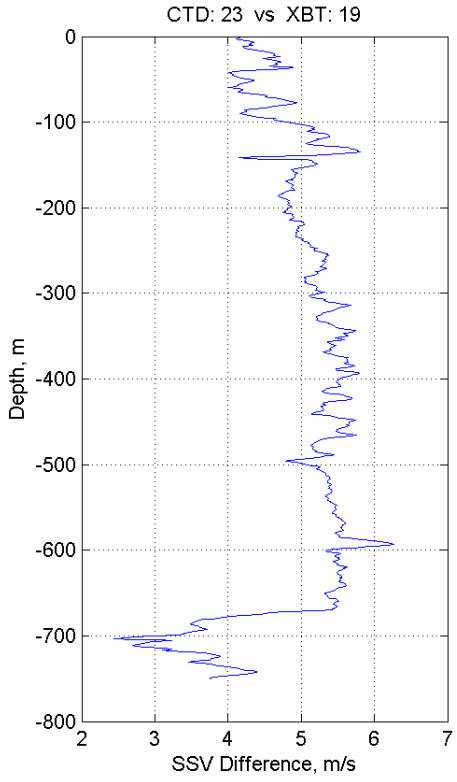

CTD: 22 vs XBT: 18
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6

APPENDIX C

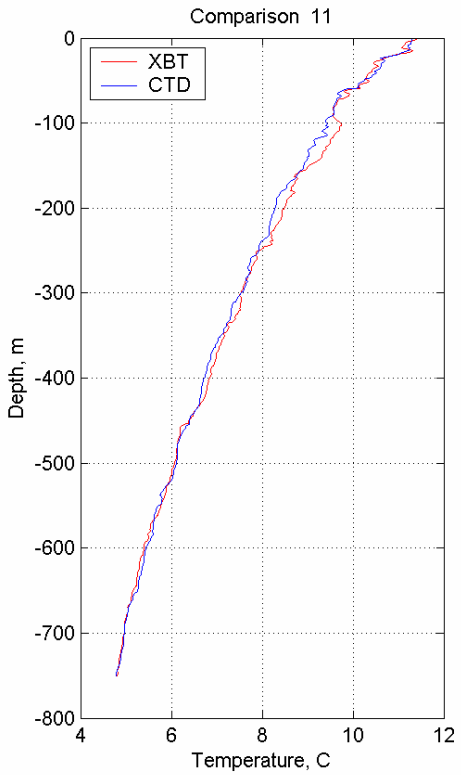

Comparison 10
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

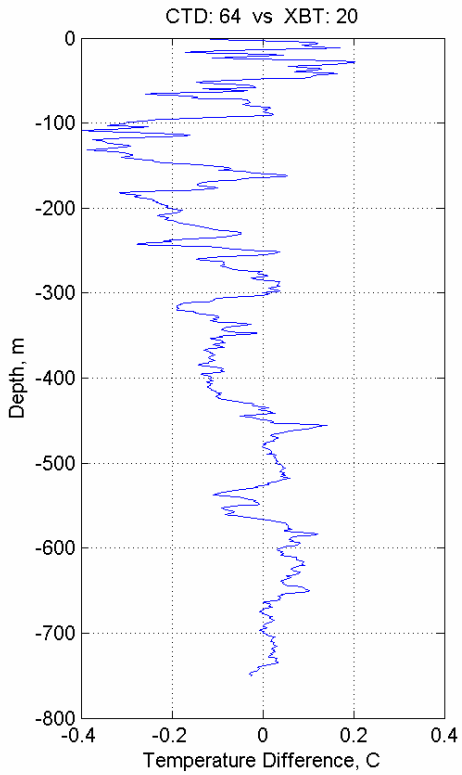

CTD: 23 vs XBT: 19
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-1
-0.5
0
0.5

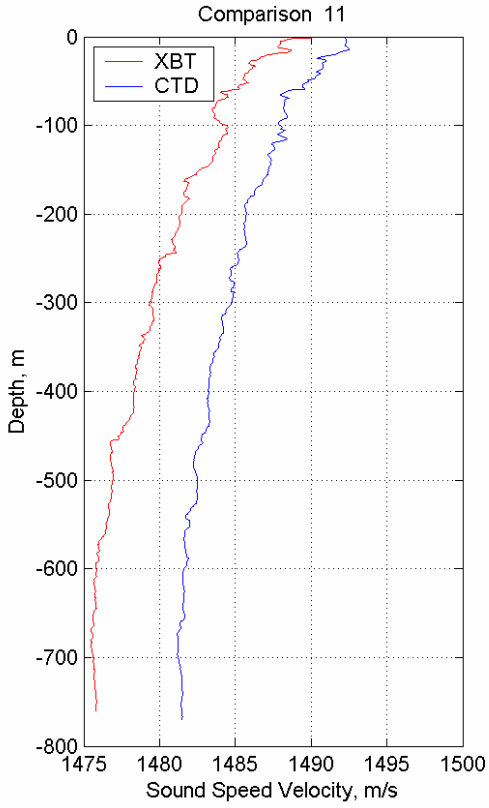

Comparison 10
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495

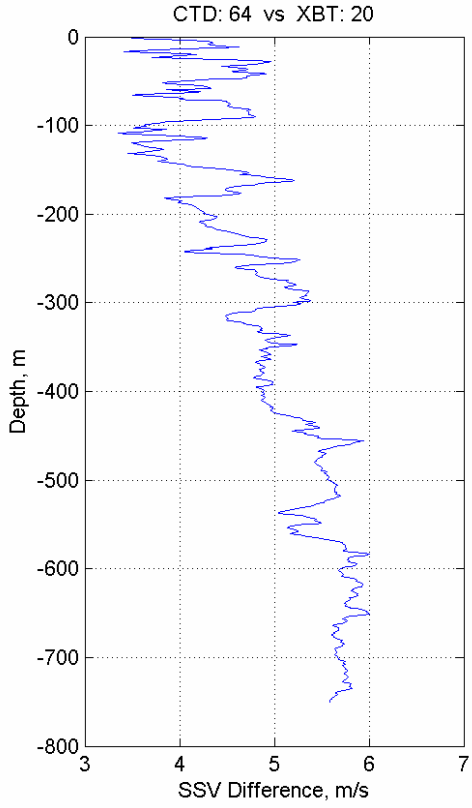

CTD: 23 vs XBT: 19
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
2
3
4
5
6
7

APPENDIX C

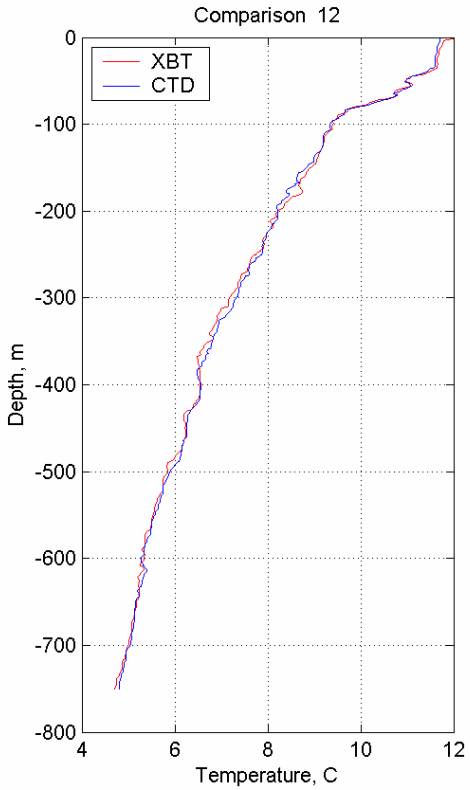

Comparison 11
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

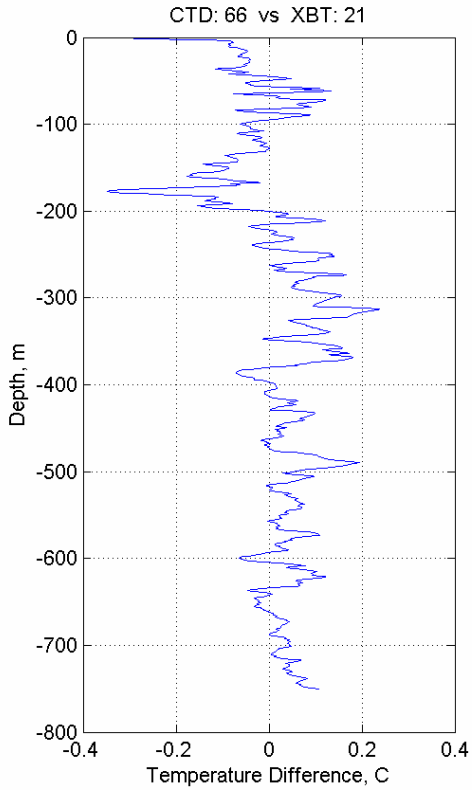

CTD: 64 vs XBT: 20
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.2
0
0.2
0.4

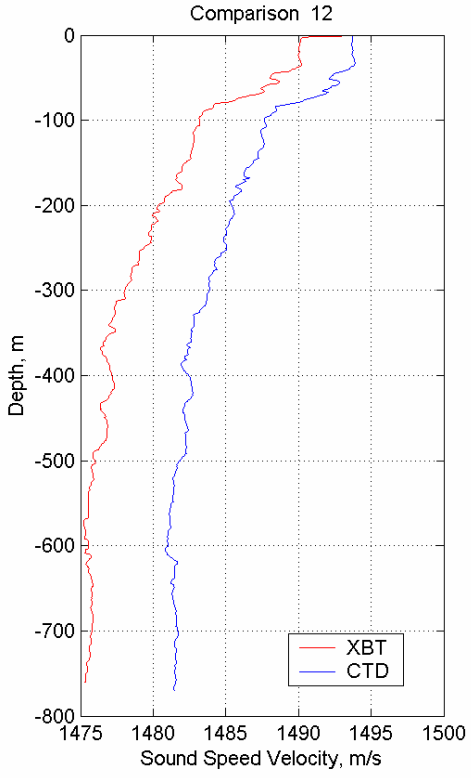

Comparison 11
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
1500

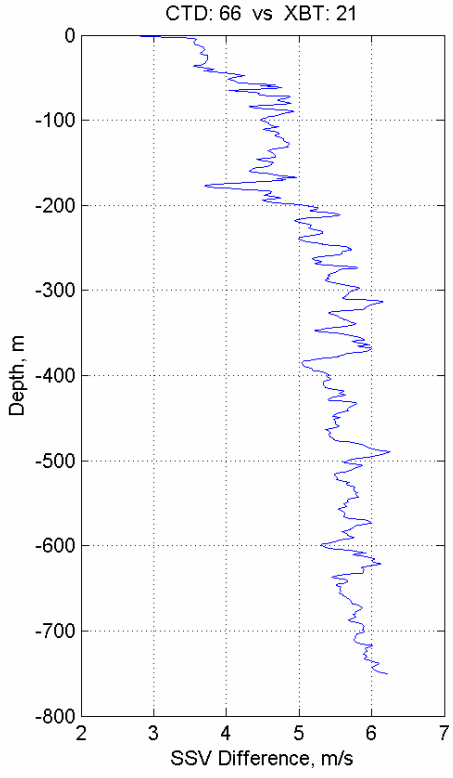

CTD: 64 vs XBT: 20
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

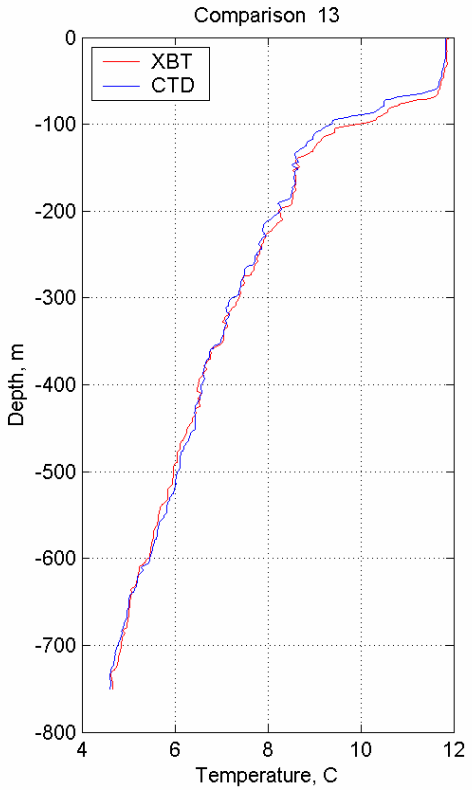

Comparison 12
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

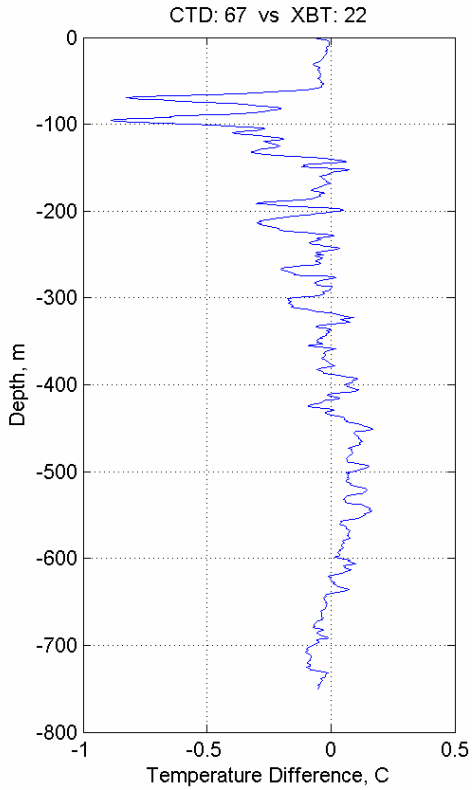

CTD: 66 vs XBT: 21
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.2
0
0.2
0.4

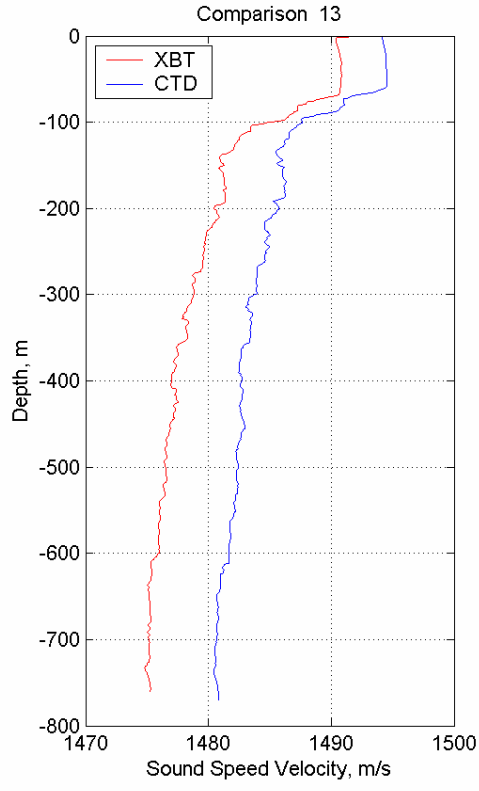

Comparison 12
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
1500

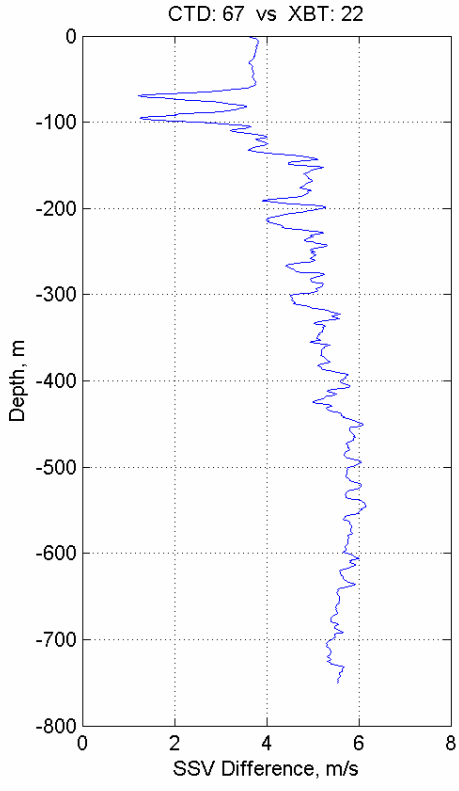

CTD: 66 vs XBT: 21
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
2
3
4
5
6
7

APPENDIX C

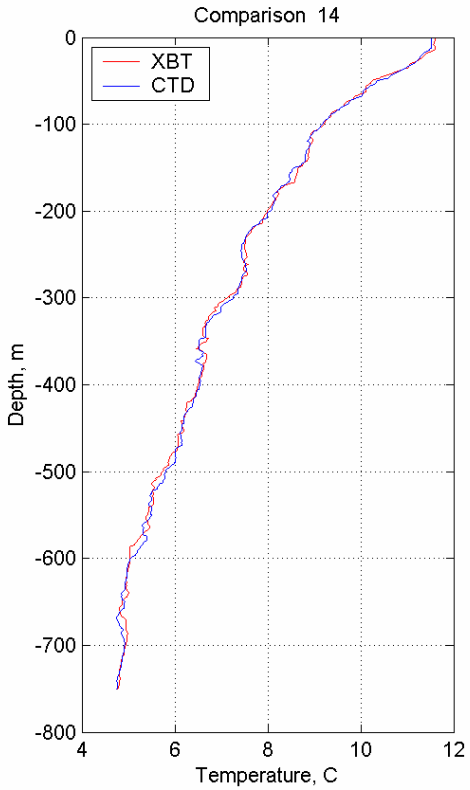

Comparison 13
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

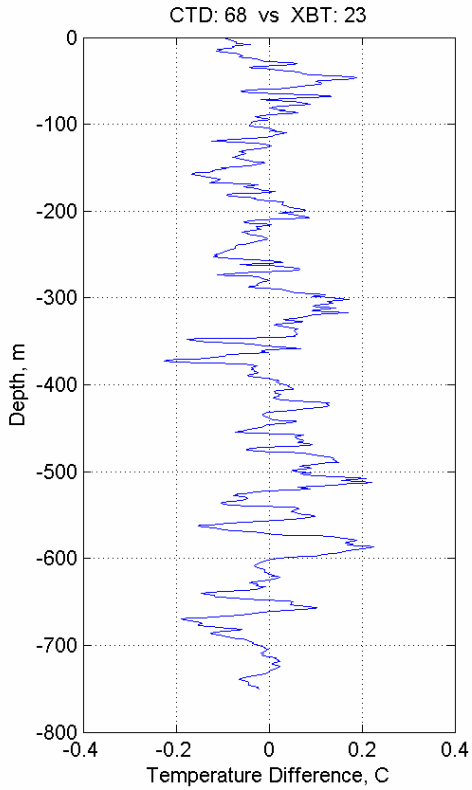

CTD: 67 vs XBT: 22
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-1
-0.5
0
0.5

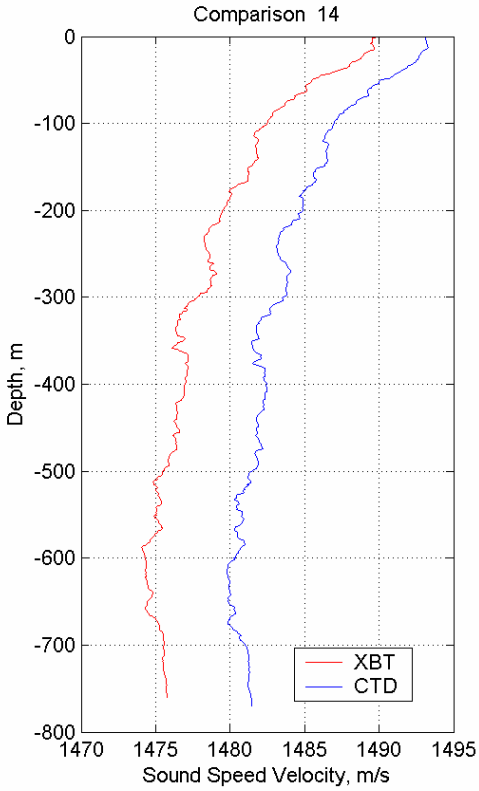

Comparison 13
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1470
1480
1490
1500

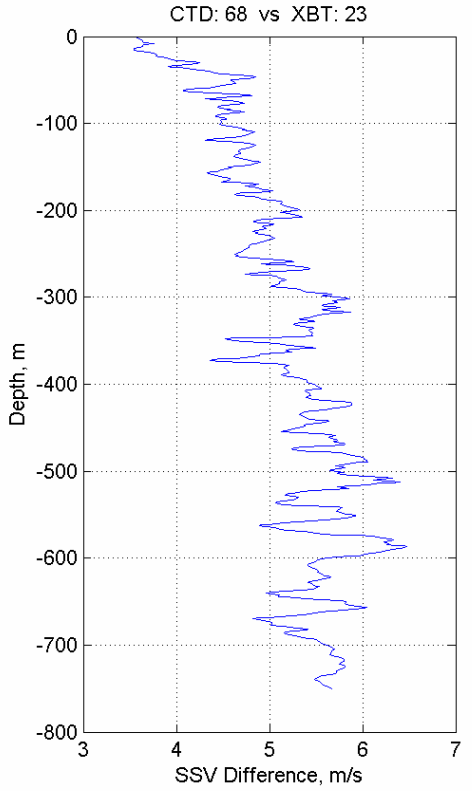

CTD: 67 vs XBT: 22
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
0
2
4
6
8

APPENDIX C

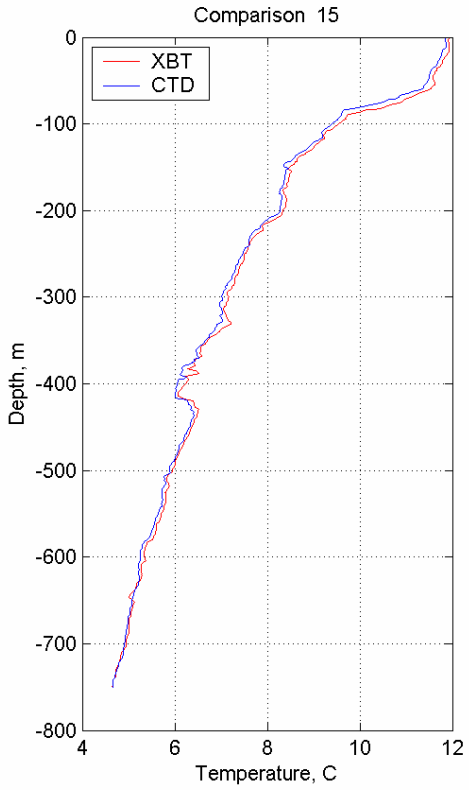

Comparison 14
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12

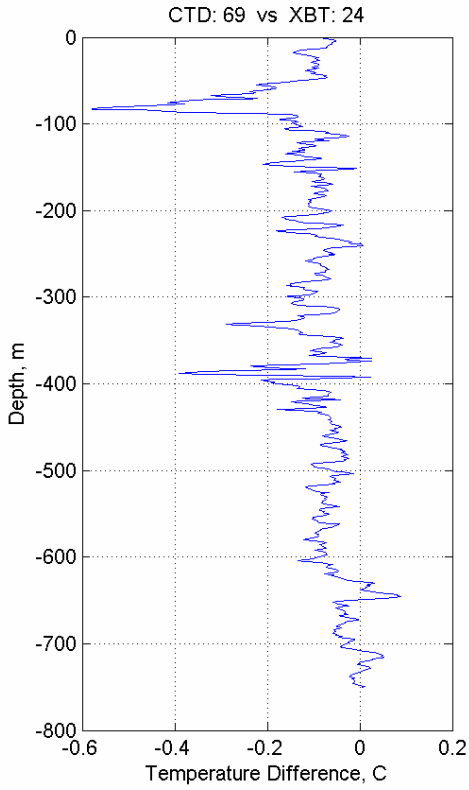

CTD: 68 vs XBT: 23
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.2
0
0.2
0.4

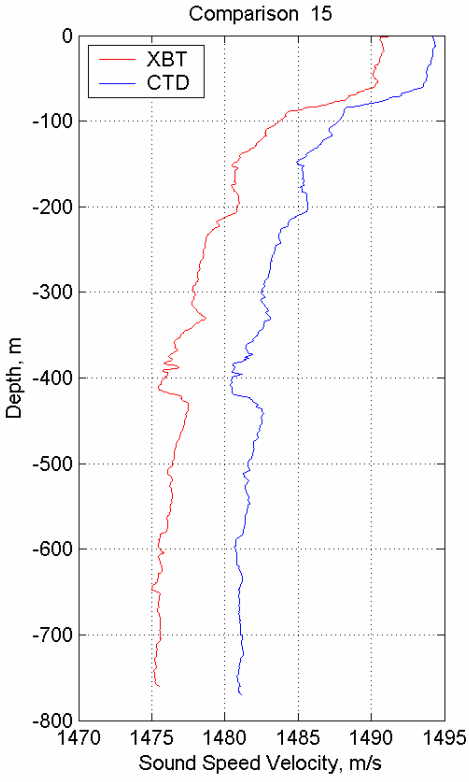

Comparison 14
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1470
1475
1480
1485
1490
1495

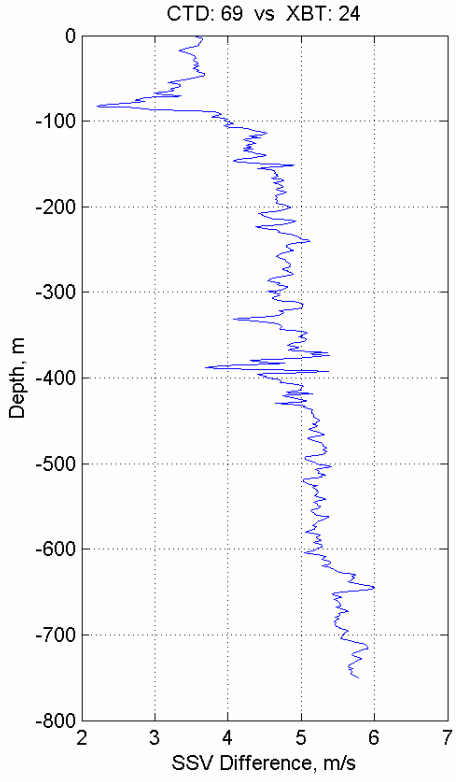

CTD: 68 vs XBT: 23
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

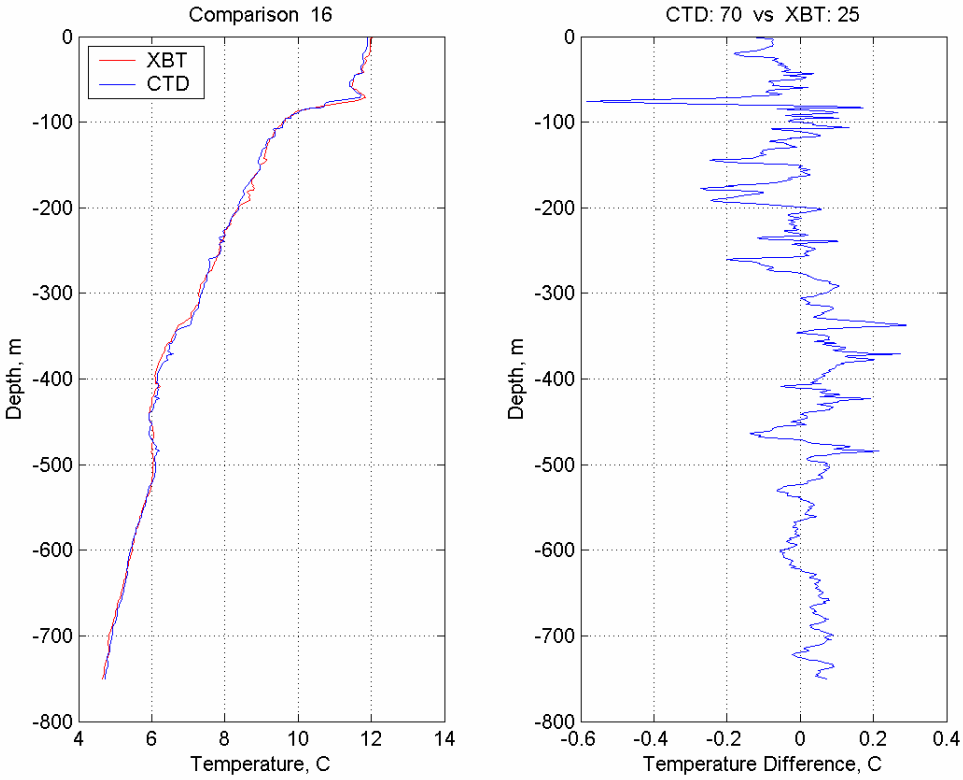

Comparison 15
XBT
CTD
Depth, m
Temperature, C

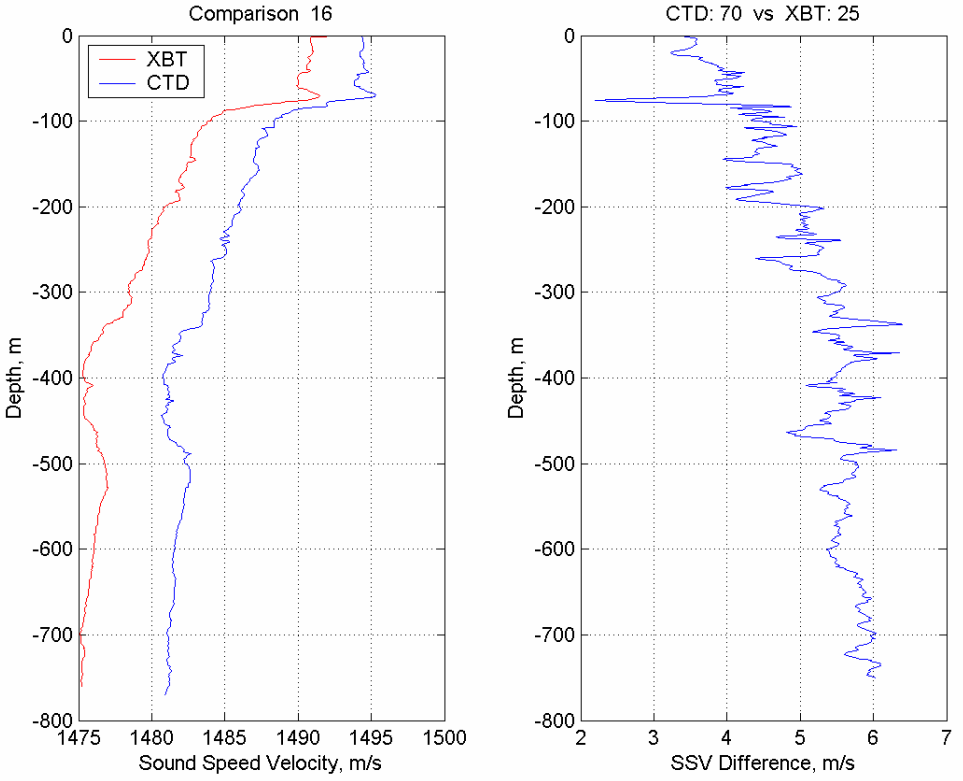

CTD: 69 vs XBT: 24
Depth, m
Temperature Difference, C


Comparison 15
XBT
CTD
Depth, m
Sound Speed Velocity, m/s

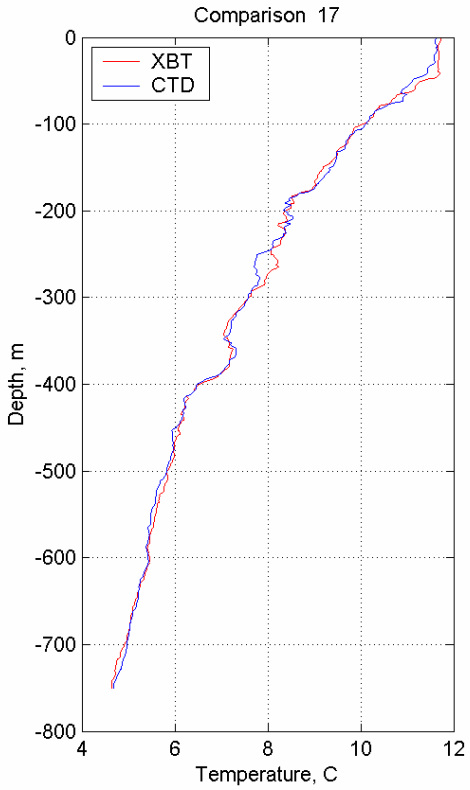

CTD: 69 vs XBT: 24
Depth, m
SSV Difference, m/s

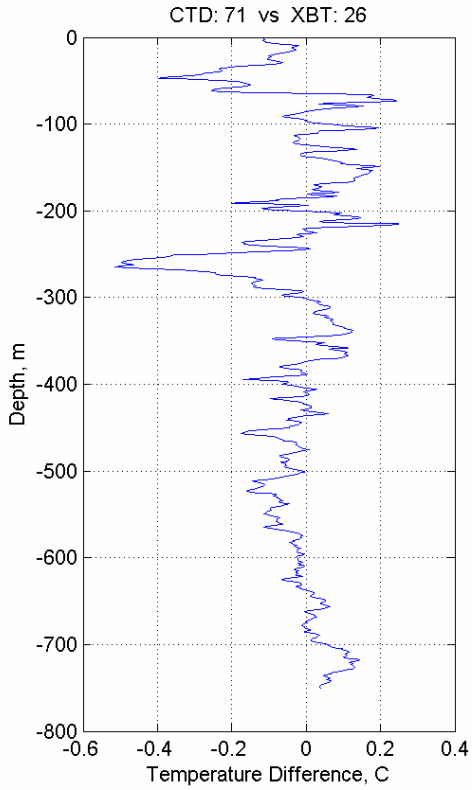
APPENDIX C

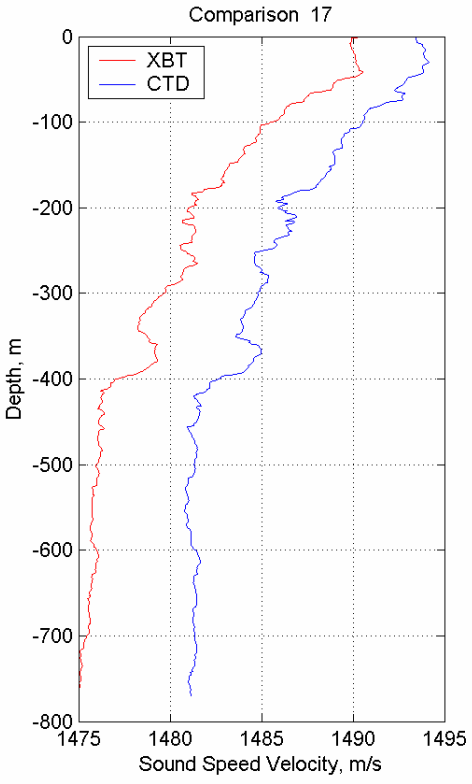

Comparison 16
XBT
CTD
Depth, m
Temperature, C
CTD: 70 vs XBT: 25
Temperature Difference, C

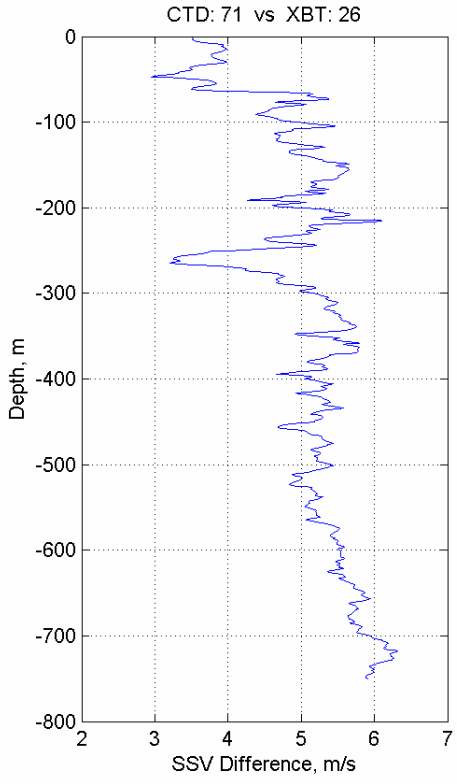

Comparison 16
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
CTD: 70 vs XBT: 25
SSV Difference, m/s

APPENDIX C

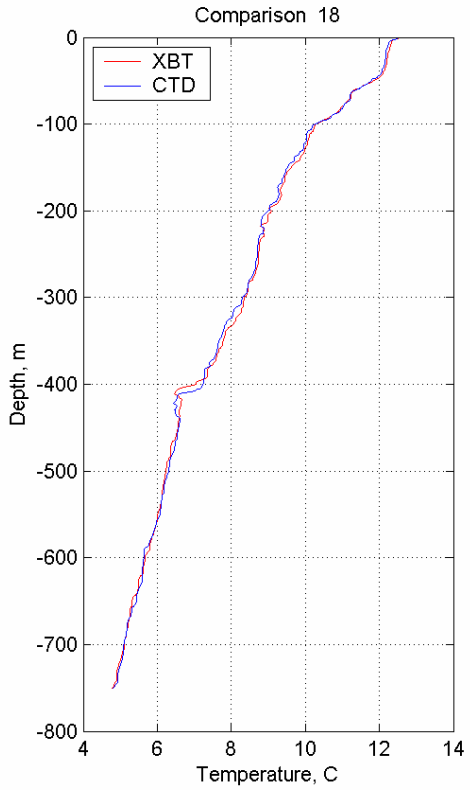

Comparison 17
XBT
CTD
Depth, m
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12
Temperature, C

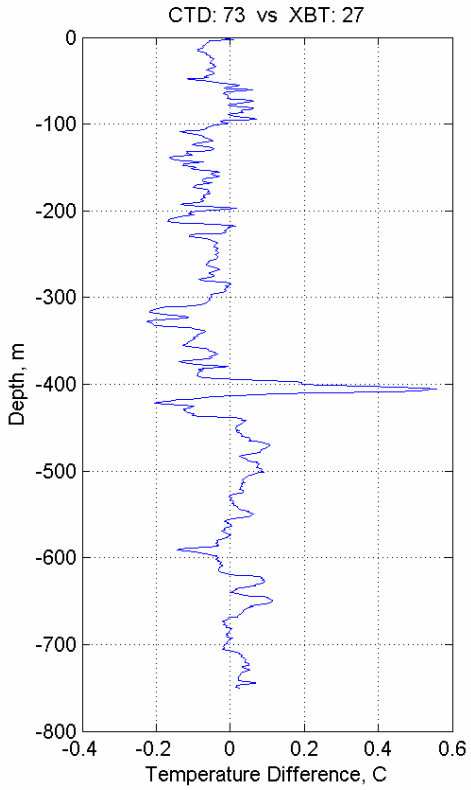

CTD: 71 vs XBT: 26
Depth, m
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.6
-0.4
-0.2
0
0.2
0.4
Temperature Difference, C

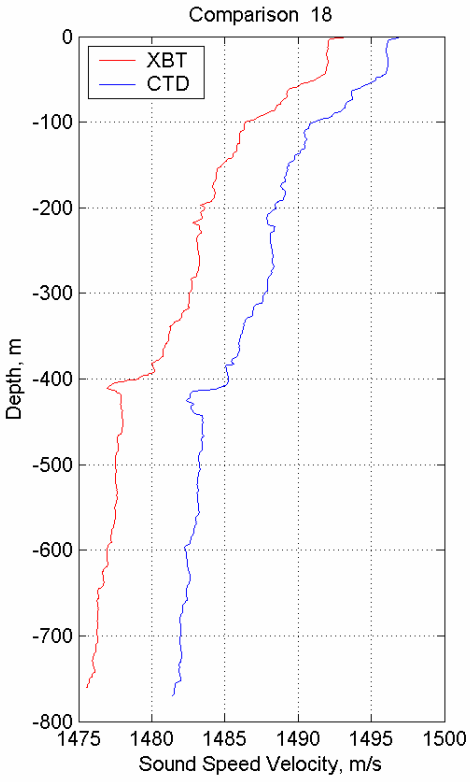

Comparison 17
XBT
CTD
Depth, m
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
Sound Speed Velocity, m/s

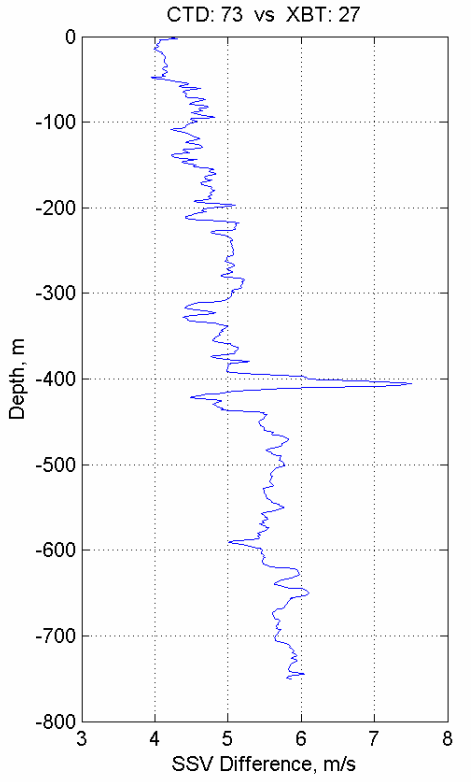

CTD: 71 vs XBT: 26
Depth, m
0
-100
-200
-300
-400
-500
-600
-700
-800
2
3
4
5
6
7
SSV Difference, m/s

APPENDIX C

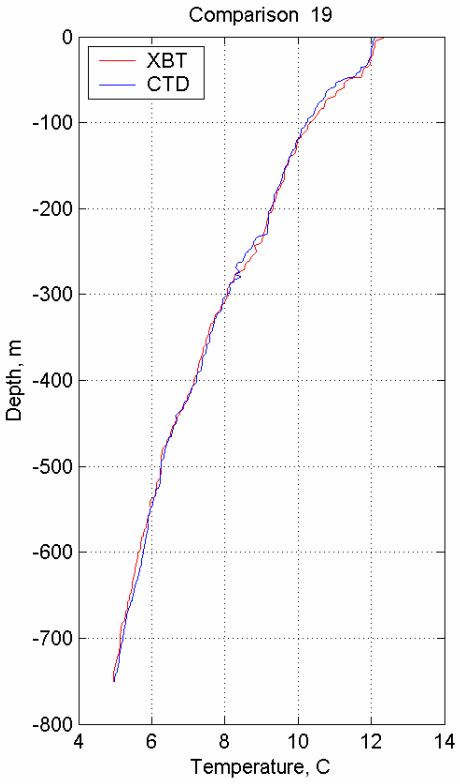

Comparison 18
XBT
CTD
Depth, m
Temperature, C

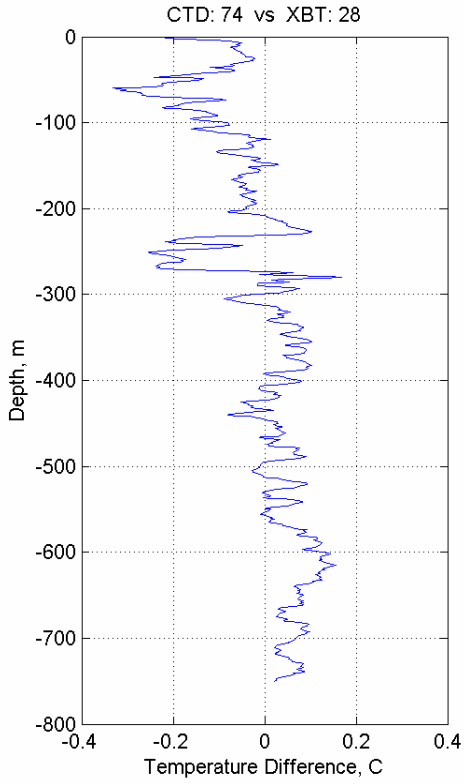

CTD: 73 vs XBT: 27
Depth, m
Temperature Difference, C

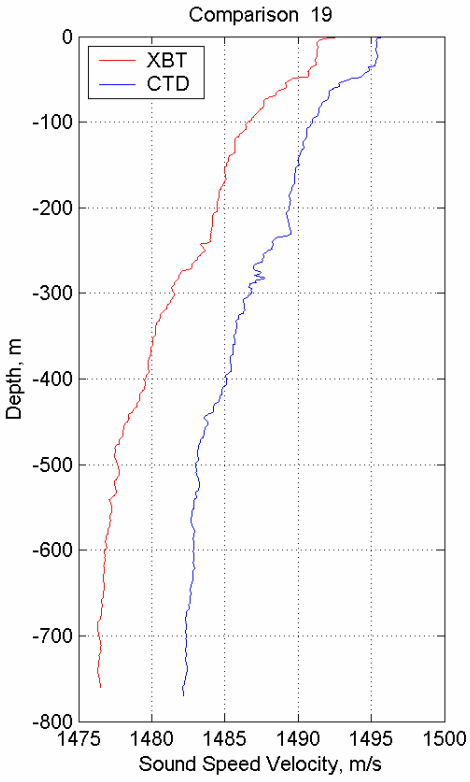

Comparison 18
XBT
CTD
Depth, m
Sound Speed Velocity, m/s

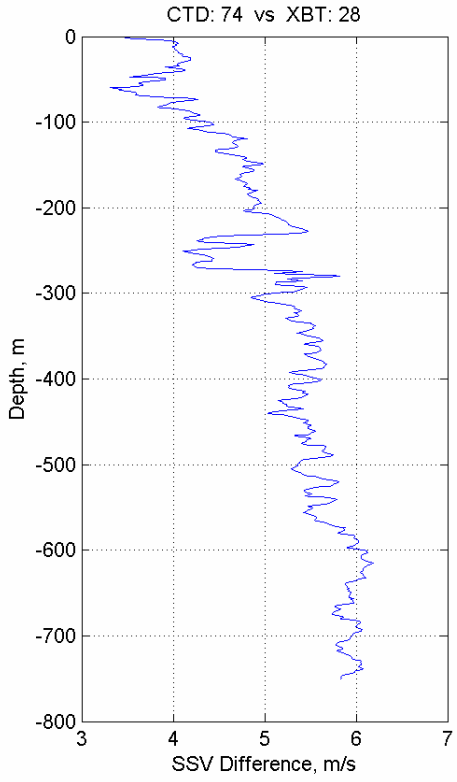

CTD: 73 vs XBT: 27
Depth, m
SSV Difference, m/s

APPENDIX C

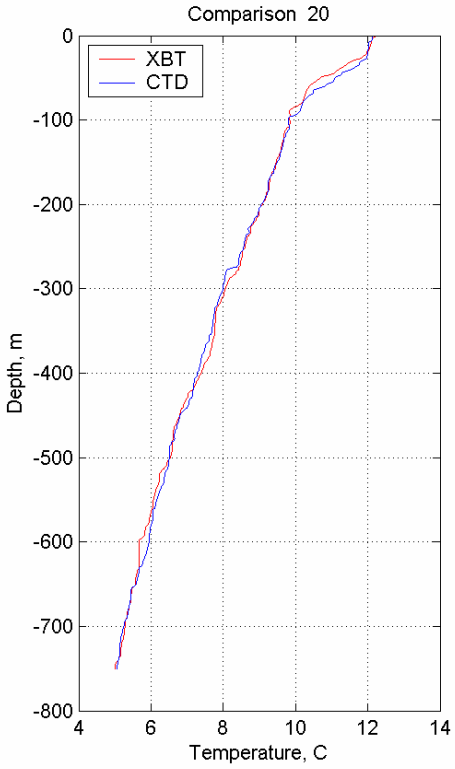

Comparison 19
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12
14

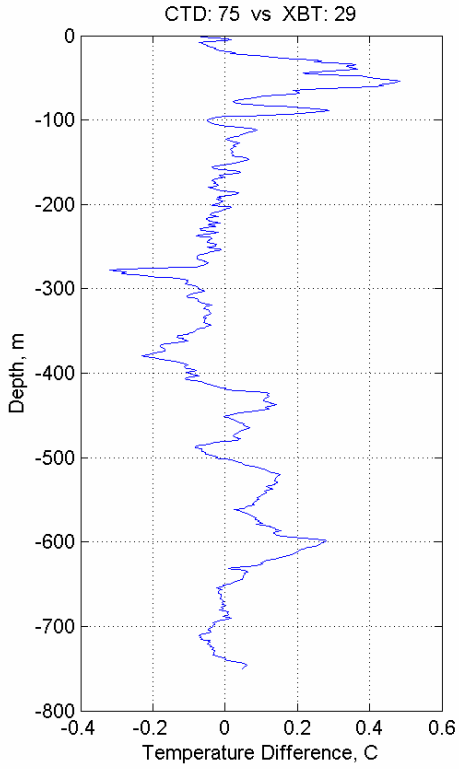

CTD: 74 vs XBT: 28
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.2
0
0.2
0.4

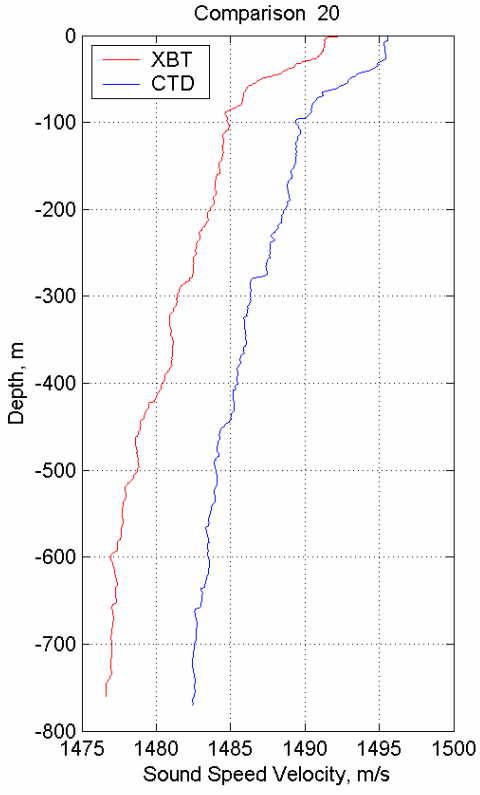

Comparison 19
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
1500

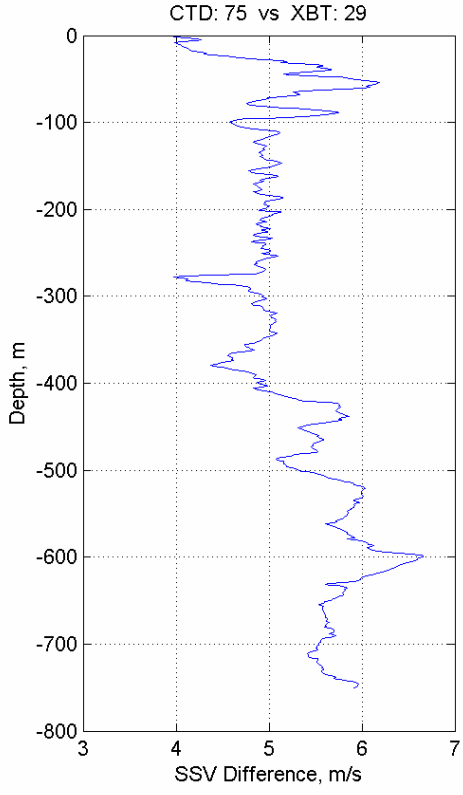

CTD: 74 vs XBT: 28
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

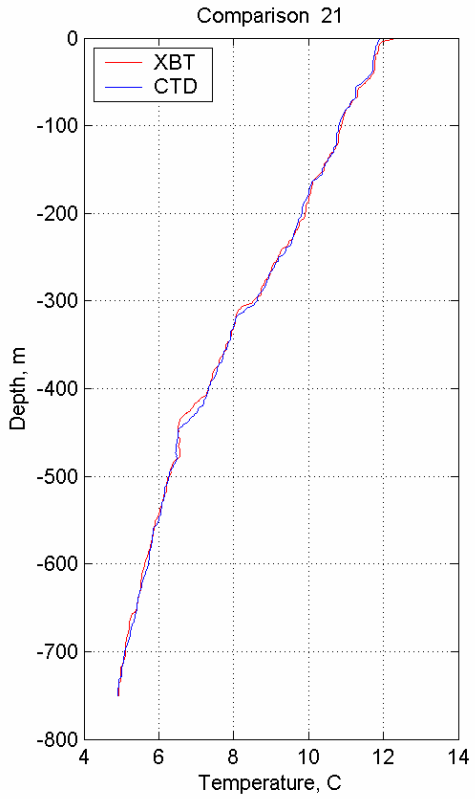

Comparison 20
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12
14

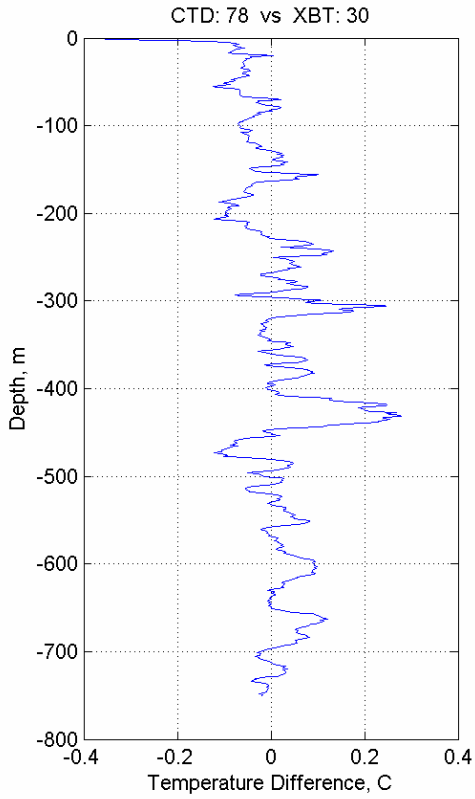

CTD: 75 vs XBT: 29
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.2
0
0.2
0.4
0.6

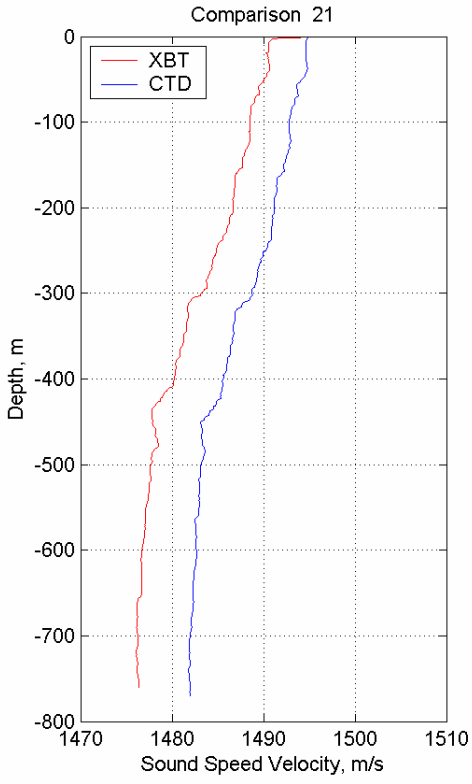

Comparison 20
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1475
1480
1485
1490
1495
1500

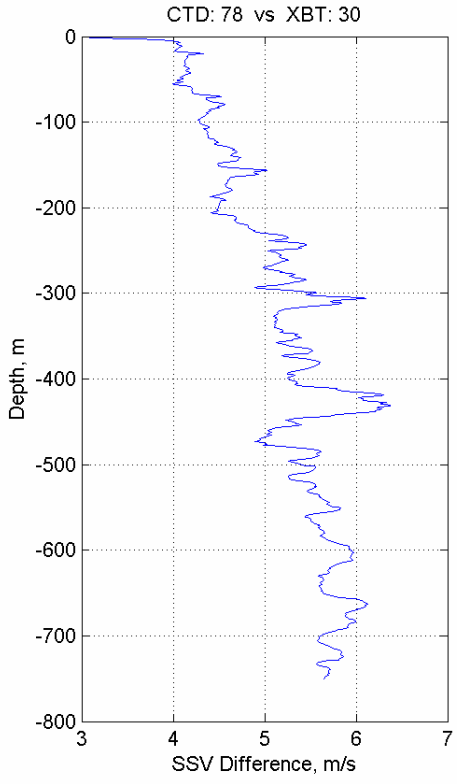

CTD: 75 vs XBT: 29
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX C

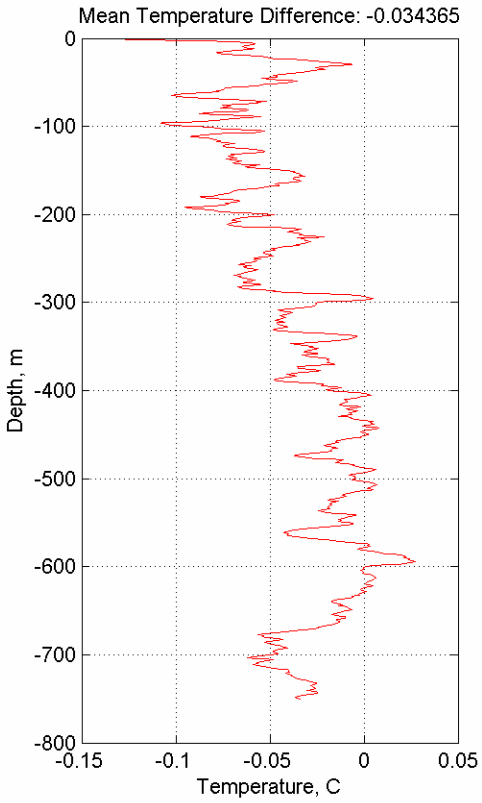

Comparison 21
XBT
CTD
Depth, m
Temperature, C
0
-100
-200
-300
-400
-500
-600
-700
-800
4
6
8
10
12
14

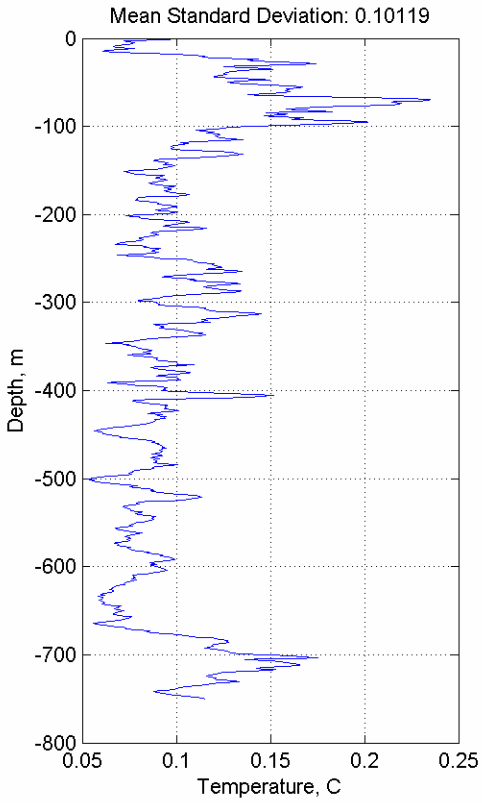

CTD: 78 vs XBT: 30
Depth, m
Temperature Difference, C
0
-100
-200
-300
-400
-500
-600
-700
-800
-0.4
-0.2
0
0.2
0.4

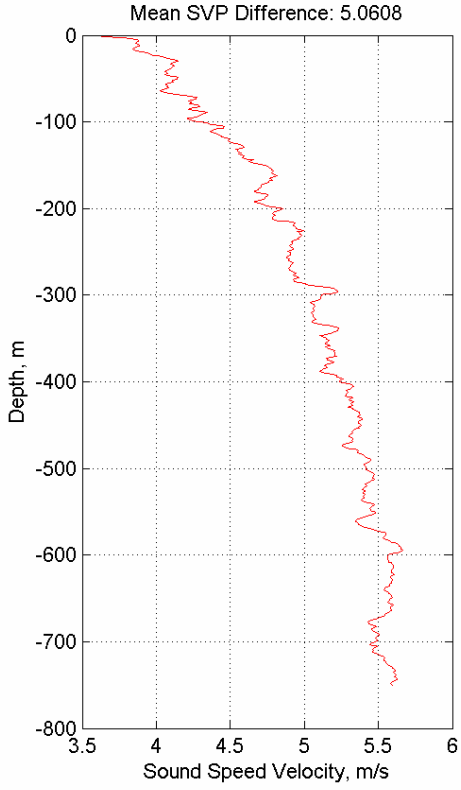

Comparison 21
XBT
CTD
Depth, m
Sound Speed Velocity, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
1470
1480
1490
1500
1510

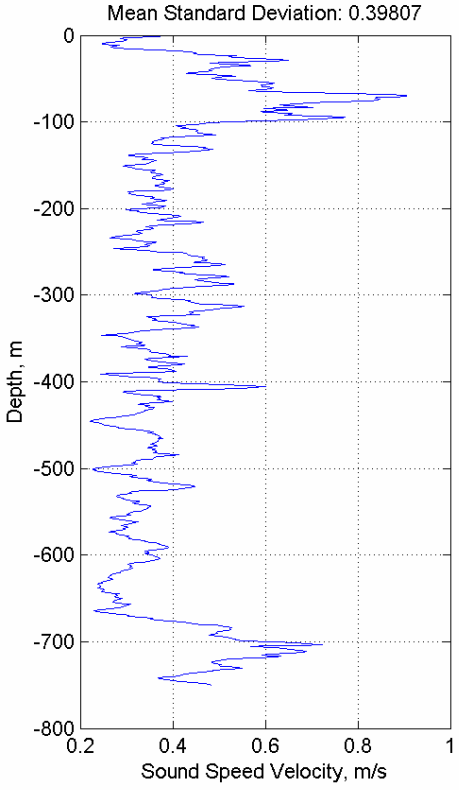

CTD: 78 vs XBT: 30
Depth, m
SSV Difference, m/s
0
-100
-200
-300
-400
-500
-600
-700
-800
3
4
5
6
7

APPENDIX D
21 CTD/XBT Pairs

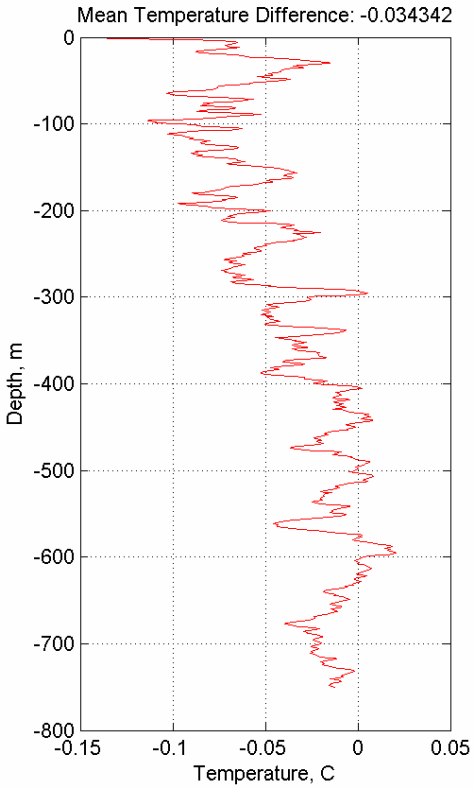


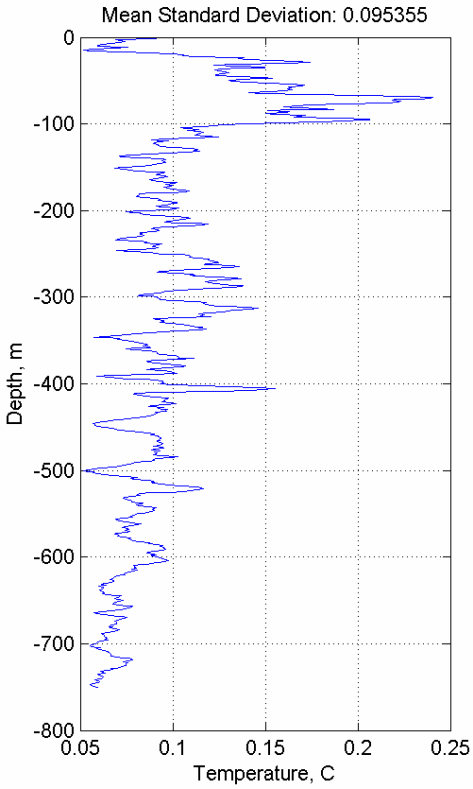


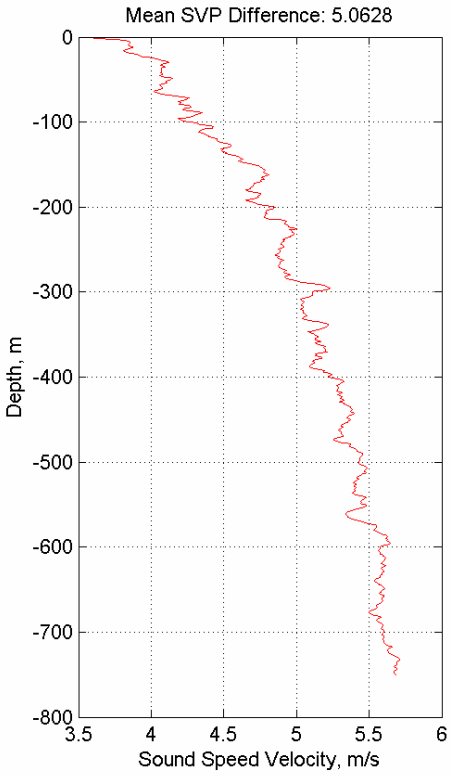


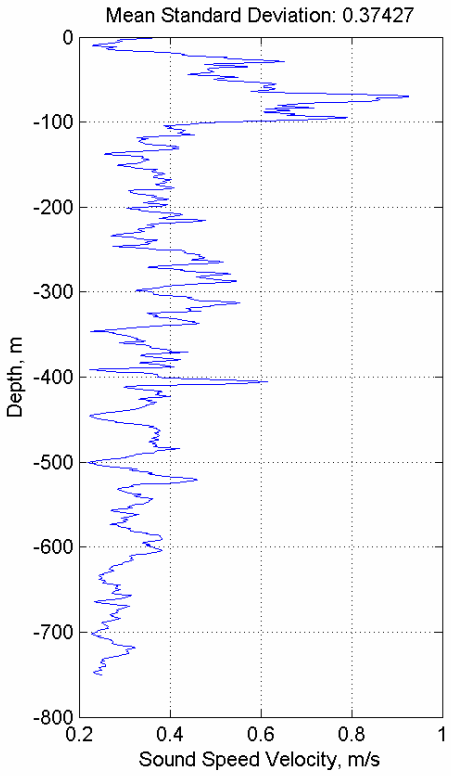


APPENDIX D
20 CTD/XBT Pairs

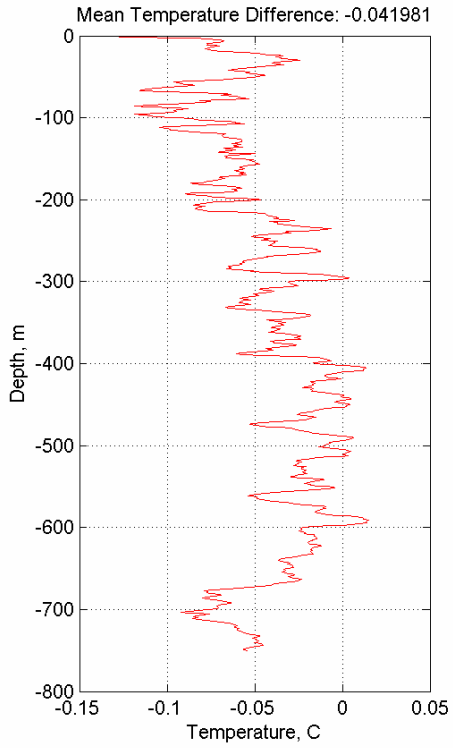


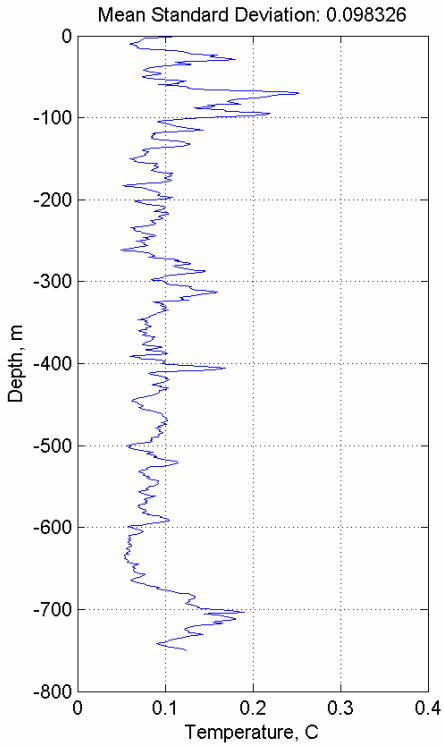


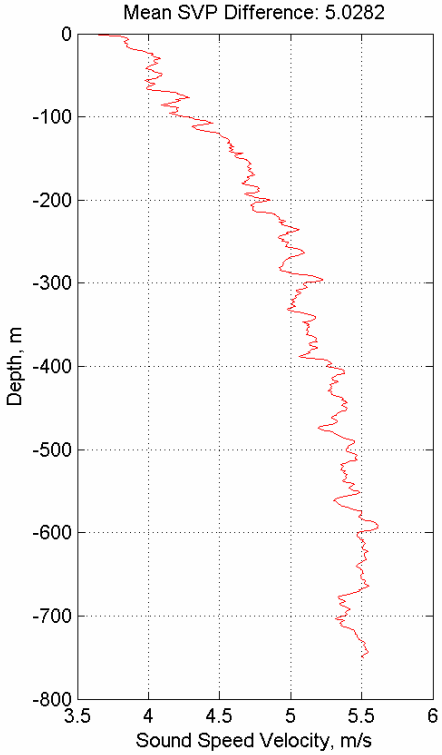


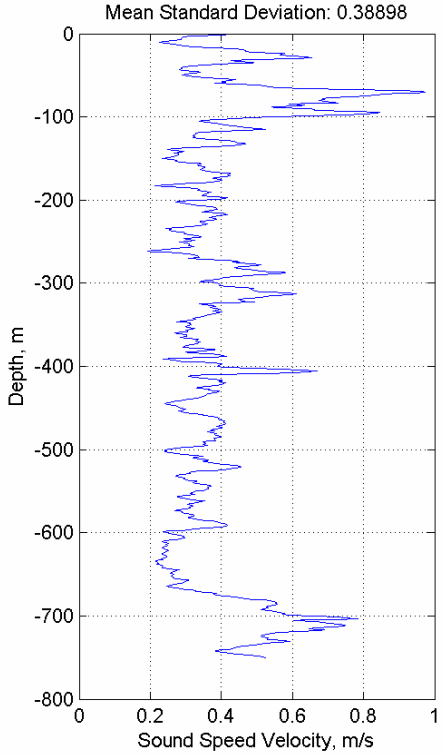


APPENDIX D
16 CTD/XBT Pairs

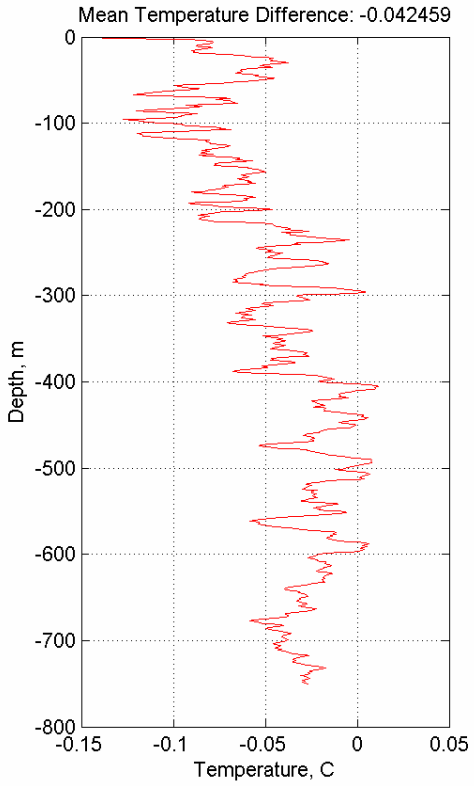


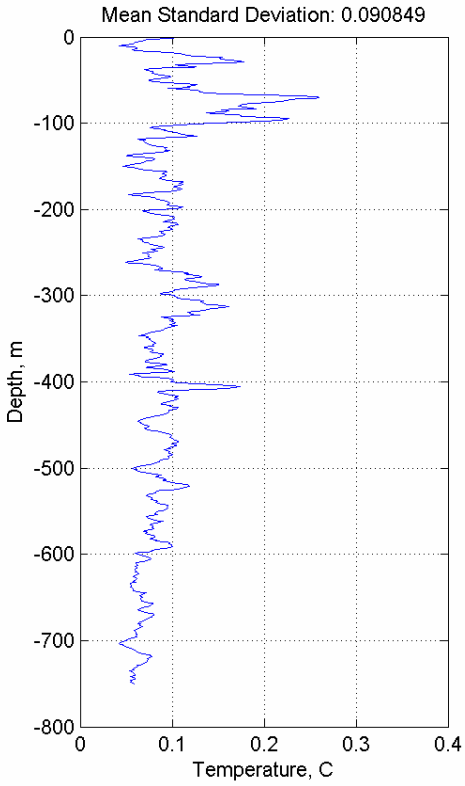


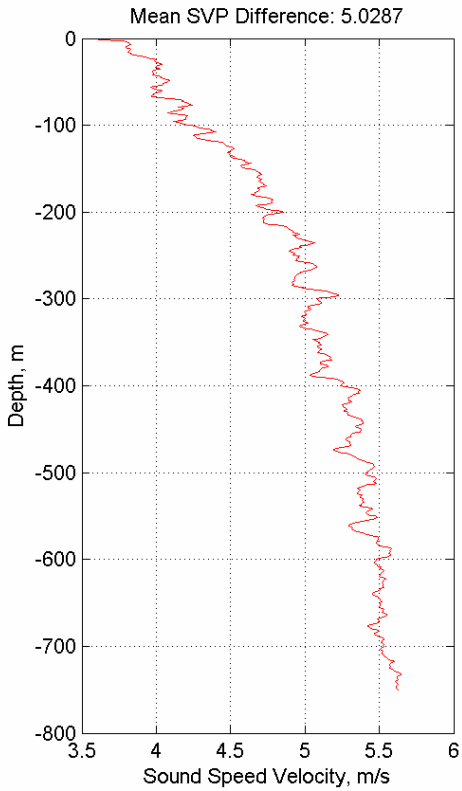


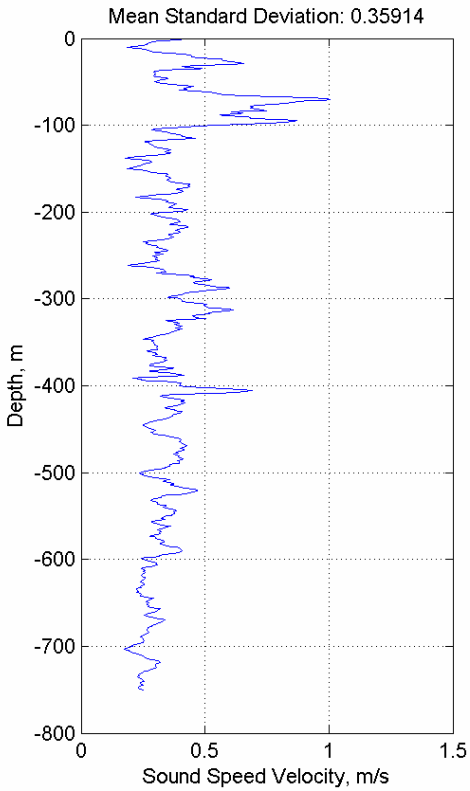


APPENDIX D
15 CTD/XBT Pairs

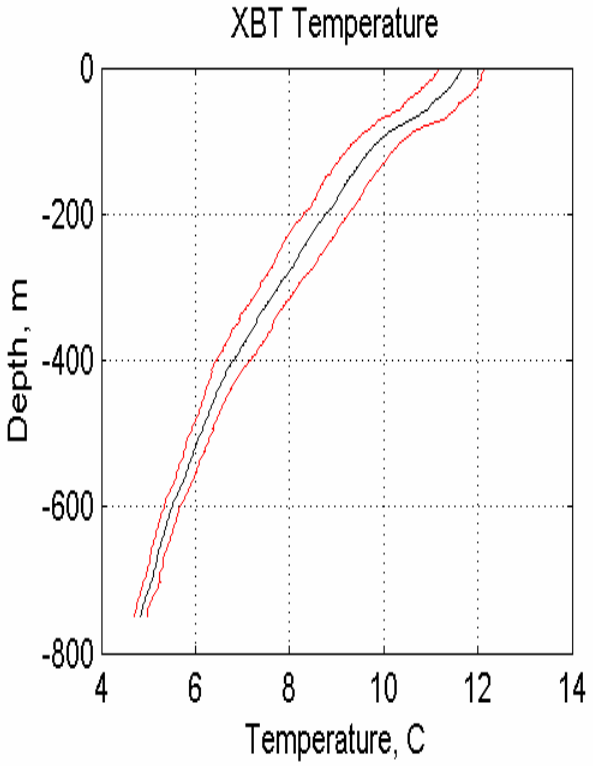


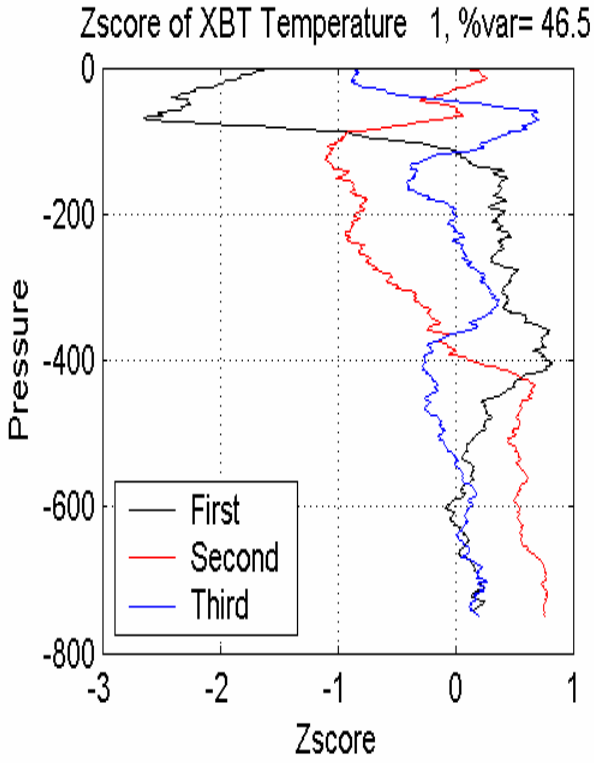


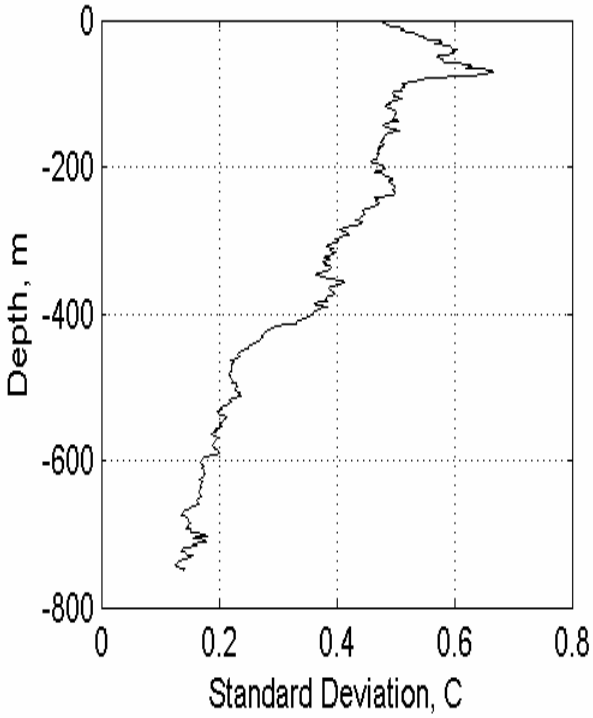


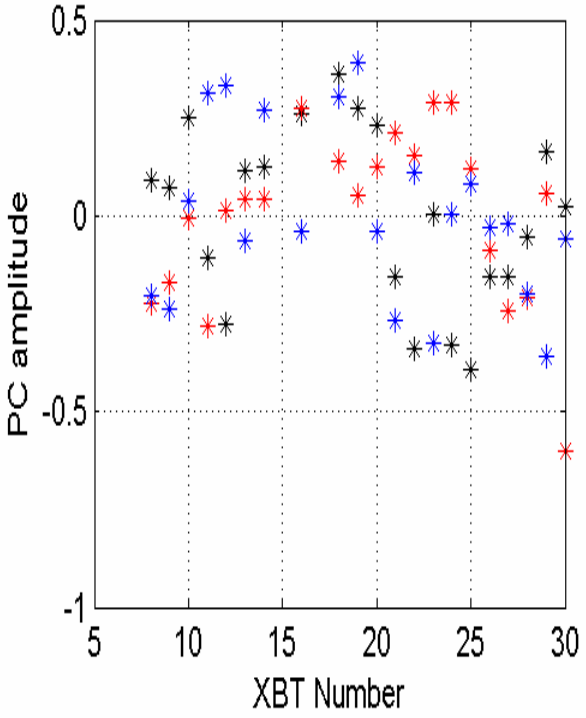


APPENDIX E
21 XBT EOF

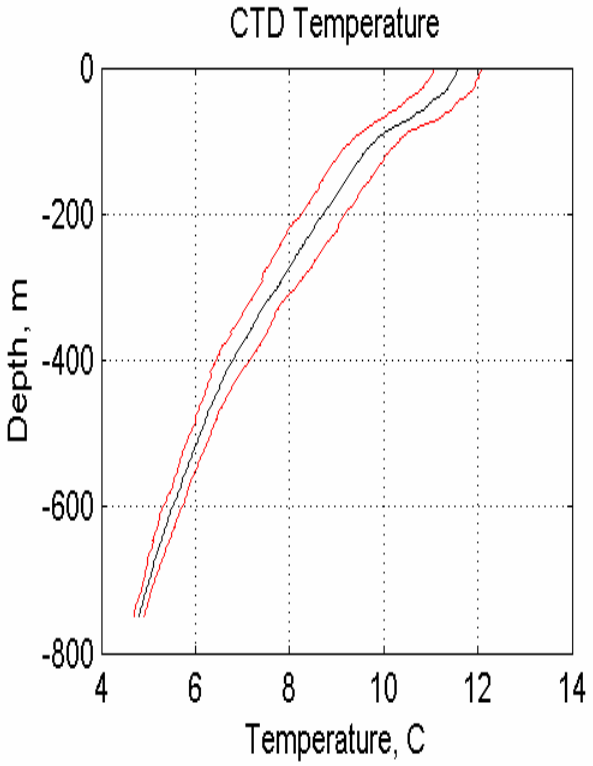


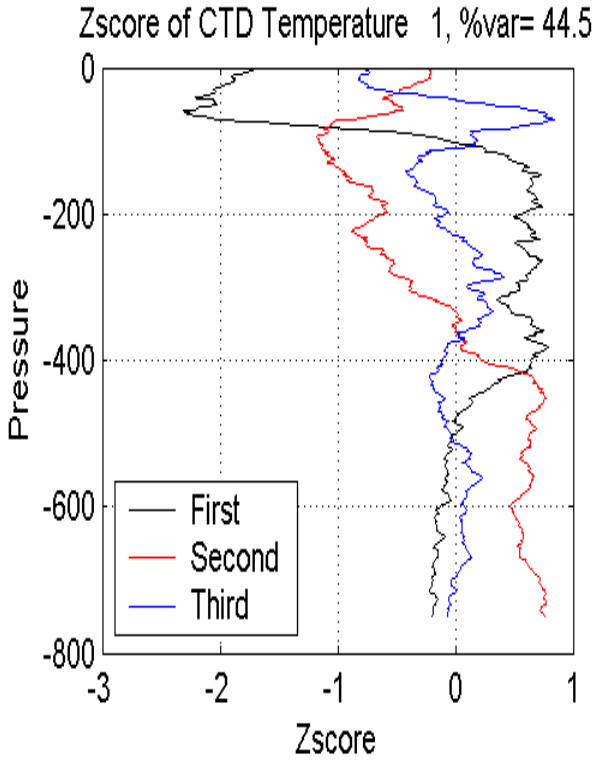


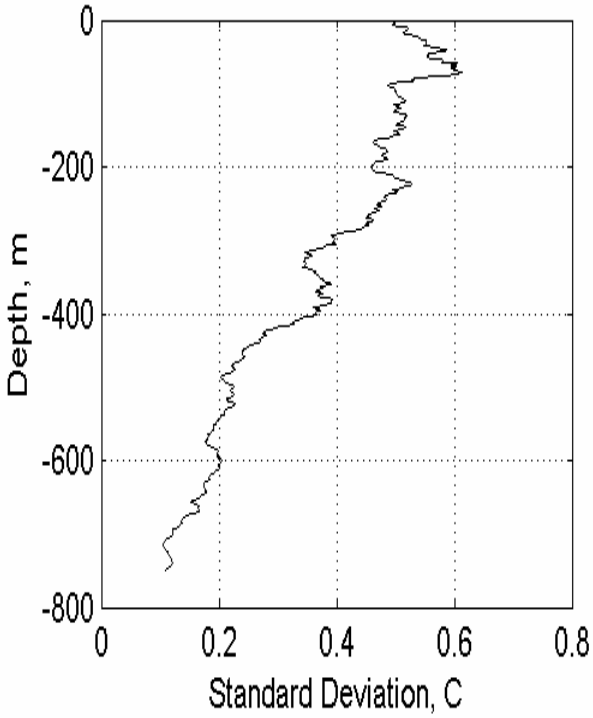


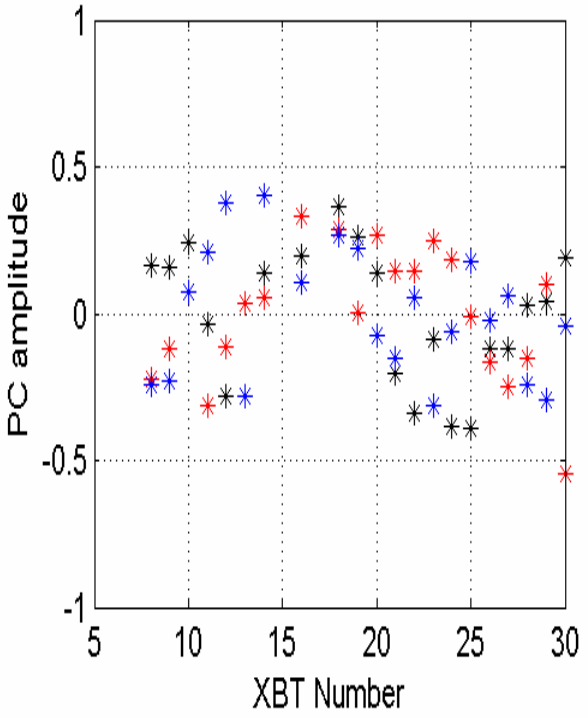


APPENDIX E
21 CTD EOF

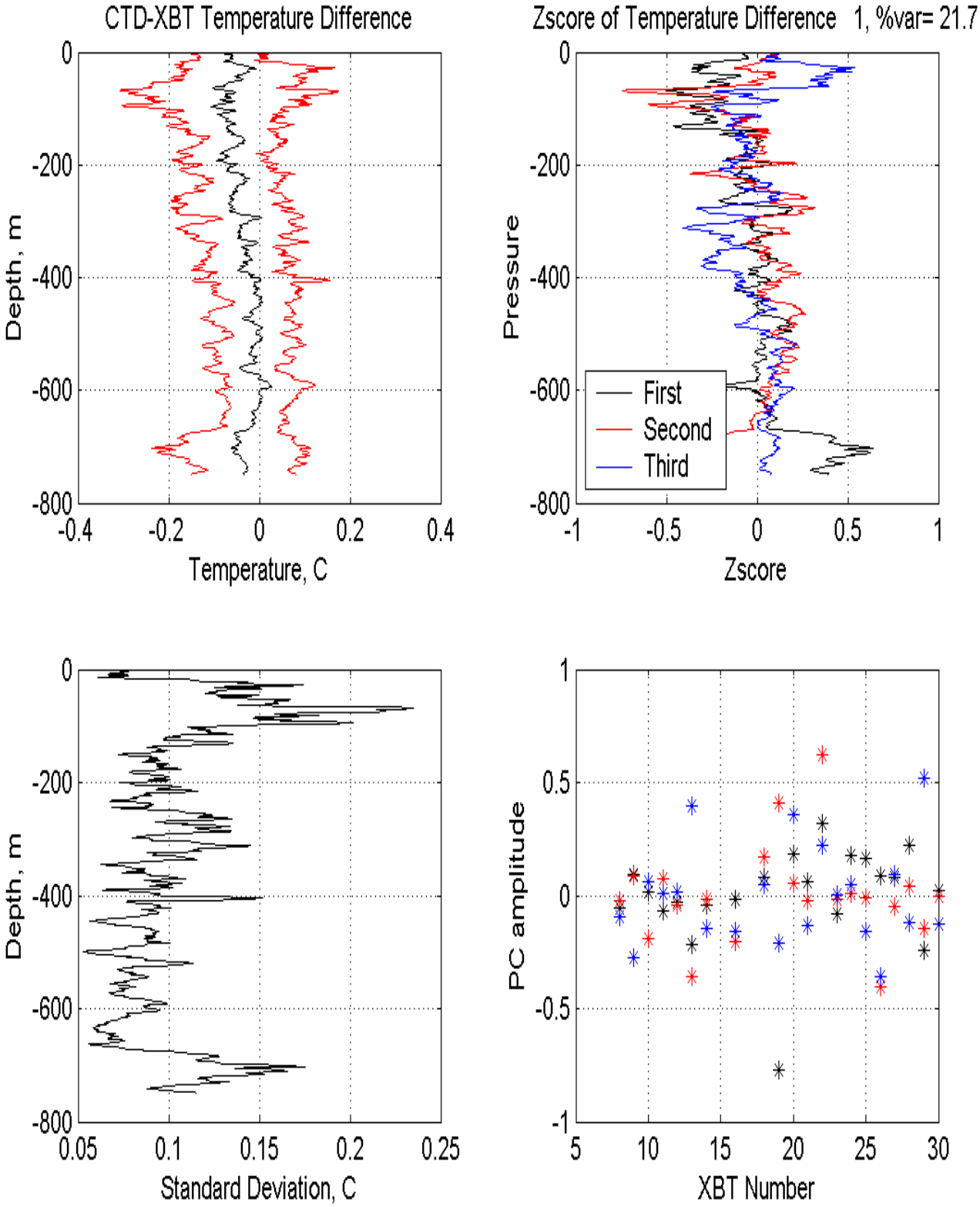
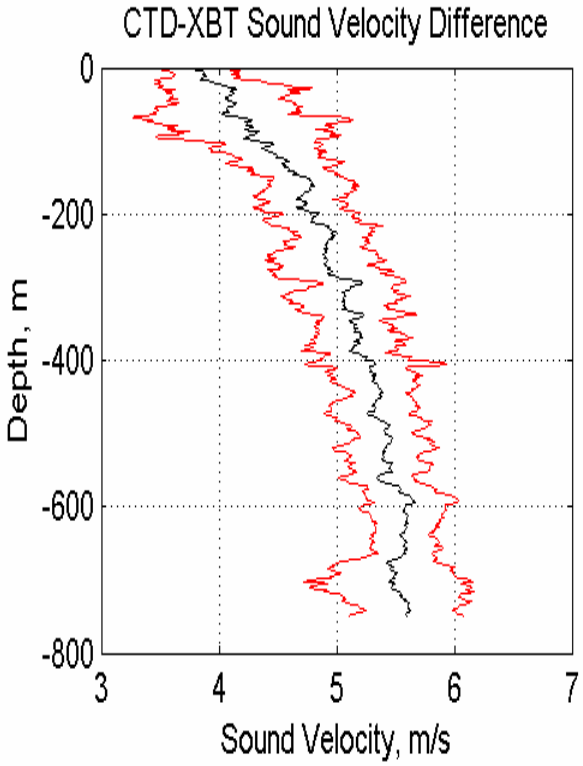
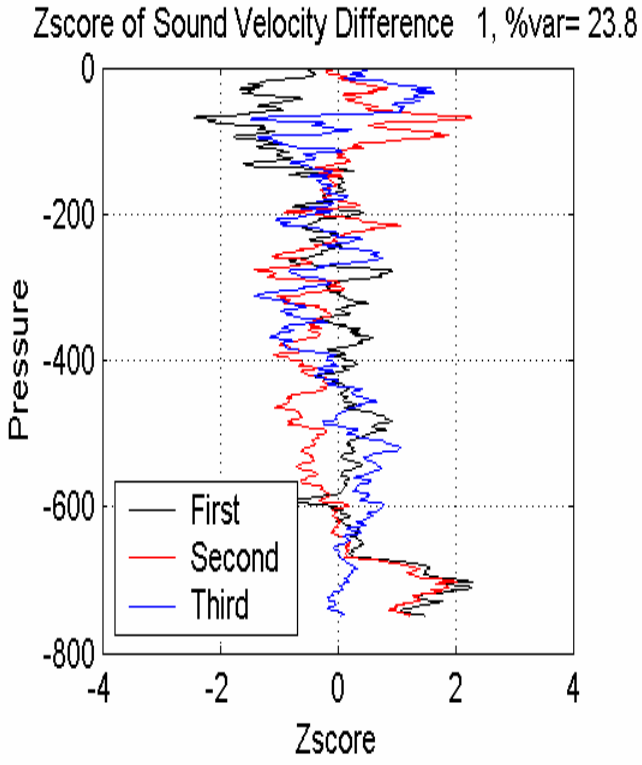
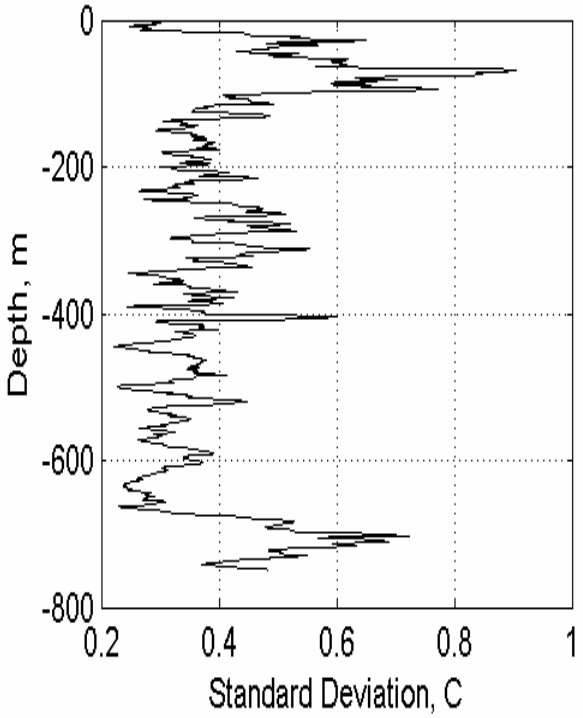
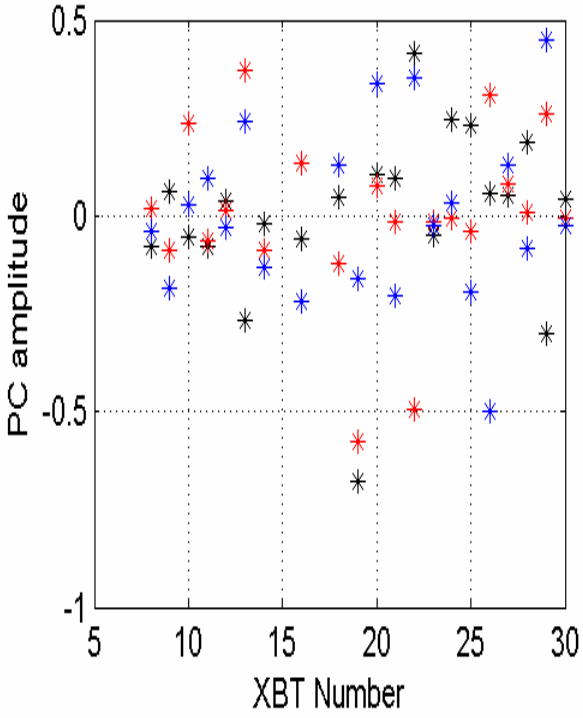








APPENDIX E
21 CTD/XBT Temperature Difference EOF



APPENDIX E
21 CTD/XBT Sound Velocity Difference EOF